

First Year Sedimentological Characteristics and Morphological Evolution of an
Artificial Berm at Fort Myers Beach, Florida

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
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College of Arts and Sciences
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Date of Approval:
June 17, 2011

Keywords: berm nourishment, nearshore sediment transport, coastal
morphodynamics, nearshore bar, beach erosion

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Report Documentation Page		<i>Form Approved OMB No. 0704-0188</i>
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1. REPORT DATE 17 JUN 2011	2. REPORT TYPE	3. DATES COVERED 00-00-2011 to 00-00-2011
4. TITLE AND SUBTITLE First Year Sedimentological Characteristics and Morphological Evolution of an Artificial Berm at Fort Myers Beach, Florida		
5a. CONTRACT NUMBER		
5b. GRANT NUMBER		
5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S)		
5d. PROJECT NUMBER		
5e. TASK NUMBER		
5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of South Florida, 4202 East Fowler Ave, Tampa, FL, 33620		
8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		
10. SPONSOR/MONITOR'S ACRONYM(S)		
11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited		
13. SUPPLEMENTARY NOTES		

14. ABSTRACT

Dredging is often conducted to maintain authorized depths in coastal navigation channels. Placement of dredged sediment in the form of nearshore berms is becoming an increasingly popular option for disposal. Compared to direct beach placement, nearshore berms have fewer environmental impacts such as shore birds and turtle nesting, and have more lenient sediment compatibility restrictions. Understanding the potential morphological and sedimentological evolution is crucial to the design of a nearshore berm. Furthermore, the artificial perturbation generated by the berm installation provides a unique opportunity to understand the equilibrium process of coastal morphodynamics. Matanzas Pass and Bowditch Point, located on the northern tip of Estero Island in west-central Florida were dredged in October 2009. The dredged material was placed approximately 600 ft offshore of Fort Myers Beach and 1.5 miles southeast of Matanzas Pass, in the form of an artificial berm. Time-series surveys and sediment sampling were conducted semi-annually in order to quantify sedimentological characteristics and morphological changes within the first year after construction of the berm. The artificial berm at Fort Myers Beach is composed mainly of fine sand. Patches of mud were found throughout the study area, with the highest concentrations being in the trough landward of the berm, and offshore southeast of the berm area. The highest concentration of carbonates was found in the swash zone, as well as at the landward toe of the berm, which coincides with the coarsest sediment. The overall mud content of the berm is lower than that of the dredged sediment, thus indicating a coarsening of the berm over time. The reduction in fines as compared to the original dredged sediment could also indicate a selective transport mechanism that moves finer material offshore, and coarser material landward, a desirable trend for artificial berm nourishment. During the course of the first year, the berm migrated landward and increased in elevation. Onshore migration occurred mostly within the first 6 months. Along with onshore migration, the shape of the berm changed from a symmetrical bell curve to an asymmetrical shape with a steep landward slope. There is no clear spatial trend of volume change alongshore within the berm area, indicating that sediment transport is mostly cross-shore dominated. A salient was formed landward of the northern portion of the berm. Several gaps were created during berm construction due to dredging and placement techniques. These dynamic gaps are likely maintained by rip currents through them. This study showed that the Fort Myers Beach berm is active, due to its landward migration during the first year after construction.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	unclassified	unclassified	Same as Report (SAR)	182	

ACKNOWLEDGEMENTS

I would like to extend my sincerest thanks to my advisor, Dr. Ping Wang, for guiding me through the completion of my thesis. His expertise both in the field and in the lab was essential to the success of my project. Dr. Wang's knowledge and instruction have helped me to better understand the coastal environment and its processes, and for that I am truly grateful. I would like to thank Drs. Julie D. Rosati and Mark A. Ross for serving on my committee and for their comments and suggestions. I would also like to thank the United States Army Corps of Engineers Coastal Inlet Research Program for funding my research, and the University of South Florida for financially supporting me.

I am extremely lucky to have the support of my fellow students and friends in the Coastal Research Lab. I would like to thank Tiffany Roberts for listening to all of my thoughts and questions relating to my project from basic coastal science to field techniques and offering her suggestions and knowledge and also Mark Horwitz for his lessons on how to operate and prepare many of the necessary pieces of equipment for my field work. I am also grateful for the help of Mike Cook and Jun Cheng who assisted me during the long field days gathering the data for this study.

Finally, I would like to thank my family and friends for their continuous support and for constantly encouraging me and believing in me.

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ABSTRACT

Dredging is often conducted to maintain authorized depths in coastal navigation channels. Placement of dredged sediment in the form of nearshore berms is becoming an increasingly popular option for disposal. Compared to direct beach placement, nearshore berms have fewer environmental impacts such as shore birds and turtle nesting, and have more lenient sediment compatibility restrictions. Understanding the potential morphological and sedimentological evolution is crucial to the design of a nearshore berm. Furthermore, the artificial perturbation generated by the berm installation provides a unique opportunity to understand the equilibrium process of coastal morphodynamics.

Matanzas Pass and Bowditch Point, located on the northern tip of Estero Island in west-central Florida were dredged in October 2009. The dredged material was placed approximately 600 ft offshore of Fort Myers Beach and 1.5 miles southeast of Matanzas Pass, in the form of an artificial berm. Time-series surveys and sediment sampling were conducted semi-annually in order to quantify sedimentological characteristics and morphological changes within the first year after construction of the berm.

The artificial berm at Fort Myers Beach is composed mainly of fine sand. Patches of mud were found throughout the study area, with the highest

concentrations being in the trough landward of the berm, and offshore southeast of the berm area. The highest concentration of carbonates was found in the swash zone, as well as at the landward toe of the berm, which coincides with the coarsest sediment. The overall mud content of the berm is lower than that of the dredged sediment, thus indicating a coarsening of the berm over time. The reduction in fines as compared to the original dredged sediment could also indicate a selective transport mechanism that moves finer material offshore, and coarser material landward, a desirable trend for artificial berm nourishment.

During the course of the first year, the berm migrated landward and increased in elevation. Onshore migration occurred mostly within the first 6 months. Along with onshore migration, the shape of the berm changed from a symmetrical bell curve to an asymmetrical shape with a steep landward slope. There is no clear spatial trend of volume change alongshore within the berm area, indicating that sediment transport is mostly cross-shore dominated. A salient was formed landward of the northern portion of the berm. Several gaps were created during berm construction due to dredging and placement techniques. These dynamic gaps are likely maintained by rip currents through them. This study showed that the Fort Myers Beach berm is active, due to its landward migration during the first year after construction.

INTRODUCTION

Dredging is often conducted to maintain authorized depths in coastal navigation channels. As part of regional sediment management, the dredged material is often used for nearby shore protection. One method to dispose of clean dredged sand is to place the sand directly on the adjacent beach in the form of beach fill. The other is placement of a submerged berm in the nearshore.

The concept of a nearshore berm was first realized in the mid-1930s when dredged material was placed offshore of Santa Barbara, California in hopes that the sediment would nourish the downdrift beaches (Dean and Dalrymple, 2002). After several attempted sites were deemed to be unsuccessful as the berms did not perform as intended, the idea was abandoned until the 1970s (Otay, 1994). More recently the notion of dredged material being placed in the nearshore has become popular once again because of the potential benefits including wave dissipation for erosion mitigation, indirectly nourishing the beach by migrating onshore, the possibility of the placement serving as a fish habitat, adding sediment to the littoral system, and more lenient restrictions on native sediment compatibility than beach fill.

From an engineering point of view, nearshore berms can be designed in an attempt to be active or stable berms depending on their intended use. Active and feeder berms can migrate onshore and nourish the beach, and stable berms

stay in the same place with the possibility of acting as a breakwater to mitigate erosion. Whether the berm is active or stable depends largely on the design specifications of the berm (i.e. the height, length, width, and side slopes), grain sizes and distribution of the sediment, and the depth at which the berm is placed. Other factors include hydrodynamic conditions as well as the background morphology of the region.

By artificially creating a nearshore morphological feature, the berm placement provides a unique opportunity to study coastal morphodynamics. The artificial berm represents an “out-of-equilibrium” morphological feature. Time-series evolution of its morphology provides insights on beach profile equilibration and therefore, trends of sediment transport as controlled by morphological characteristics and driving hydrodynamic forcing.

The nearshore berm method of disposing of dredged material was employed in Fort Myers Beach, Florida, which is located in west-central Florida, in October 2009 after the maintenance dredging of Matanzas Pass and the north tip of Estero Island. This thesis is an initial study on the first year morphological changes and sedimentological characteristics of the berm, and berm-induced changes to the surrounding beach.

This thesis begins with a discussion of previous research on berm nourishments, including case studies of previous berm nourishments. A discussion of the study area and methods used to carry out this study is also included. Finally, a summary and discussion of the results of this study including sedimentological characteristics and morphological characteristics are presented.

Research Objectives at Fort Myers Beach Berm, Florida

The goal of this study is to quantify the temporal evolution of morphological and sedimentological characteristics of the nearshore berm located at Fort Myers Beach, Florida. This study aims to provide insights to understanding the behavior of berms and creating better predictive models of this increasingly popular disposal method of clean dredged material. Specifically, this study will touch on the role of selective transport in sediment characteristics post construction of the berm, as well as the beach profile equilibrium concept, and how the placement of a berm affects the morphodynamics in the area.

To accomplish these goals, sediment characteristics are documented across the berm and in the adjacent areas to identify any differences between the native sediment and berm sediment, and to see the distribution of sediment across the profiles in the project area and in the control areas. Morphological changes are documented both alongshore and cross-shore to ultimately quantify the evolution of the berm through the first year after its construction. Profiles are used to calculate the initial volume of the berm, as well as any changes in the overall volume of the profiles. Finally, longshore variations in the berm are examined.

PREVIOUS RESEARCH

Nearshore berm placements are becoming an increasingly popular option for the disposal of clean dredged material. Most papers written on nearshore berms are technical reports, rather than scientific papers, emphasizing the need for more research on this topic. The following section gives a summary on some of the research already performed on this type of nourishment, as well as examples of previously constructed berms.

General Design Guidelines for Berms

Larson and Kraus (1992a, 1992b, and 1994) investigated natural longshore bars at the U.S. Army Corps of Engineers Field Research Facility (FRF) in Duck, North Carolina, eventually concluding that the behavior of natural longshore bars could be analogous to the behavior of artificial berms placed in the nearshore. The project location has a two bar system: an inner bar approximately [330 ft] from the shoreline and an outer bar approximately [980 ft]. Bi-weekly cross shore surveys of the area were taken over 11 years, totaling approximately 300 surveys. From all of the surveys, Larson and Kraus created a reference profile by fitting a modified equilibrium profile to the average profile based on Dean's equilibrium beach profile (Dean, 1977), which takes into account the varying grain size cross shore using the following equation:

$$h = A_* \left[x + \frac{1}{\lambda} \left(\frac{D_0}{D_\infty} - 1 \right) (1 - e^{-\lambda x}) \right]^{2/3} \quad (1)$$

where h is the water depth, x is the cross shore distance, A_* is a shape parameter, D_0 is an equilibrium wave energy dissipation per unit volume in the inshore, D_∞ is the equilibrium wave energy dissipation per unit volume in the offshore and λ is the characteristic length describing rate at which D_0 reaches D_∞ . The authors chose a survey line with the most data during the study period as a representative line of the entire research area and compared it to the reference profile to calculate volume of the bars, and ultimately find correlations between various bar properties. The study showed that there were definite correlations between volume vs. height of the bar, volume vs. length of the bar, and depth to crest of the bar vs. distance to its center of mass. In order to correlate bar properties to wave properties, a data threshold had to be employed to include only events with marked profile change. Once the data screening was completed several correlations were found between wave properties and bar properties including $h/(H_0)_{max}$ and $(H_0/L_0)_{mean}$, and change in volume $\Delta V_b/H_0^2$ and $(H_0/wT)_{mean}$, where h is the water depth, H_0 is the offshore wave height, L_0 is the offshore wave length, ΔV_b is the change in bar volume, w is the sediment fall speed, and T is the wave period. For geometric bar properties, significant correlations were found between bar volume versus height, volume versus length, and depth to crest versus distance to mass center. The criteria from the experiment in Duck were applied to predict the movement of an artificial berm in California, and it was concluded that because the predictions and results were in

agreement, the criterion in this report on an east coast beach may apply to all coasts exposed to energetic waves.

Hallermeier (1981) proposed a model to divide a seasonal sand beach into three shore-normal zones based on mobilization of sand by waves. The zones from the nearshore are the littoral zone, the shoal zone, and the offshore zone. The shoal zone, according to Hallermeier, is bound by two water depths (Figure 1): d_s , which is maximum water depth for significant alongshore transport and intense on/offshore transport by waves during extreme conditions, and d_i which is the maximum water depth for initiation of motion of sediment by median wave conditions. Hallermeier suggests that when considering subaqueous beach nourishment, the dredged material should be placed within the littoral zone, or landward of d_i .

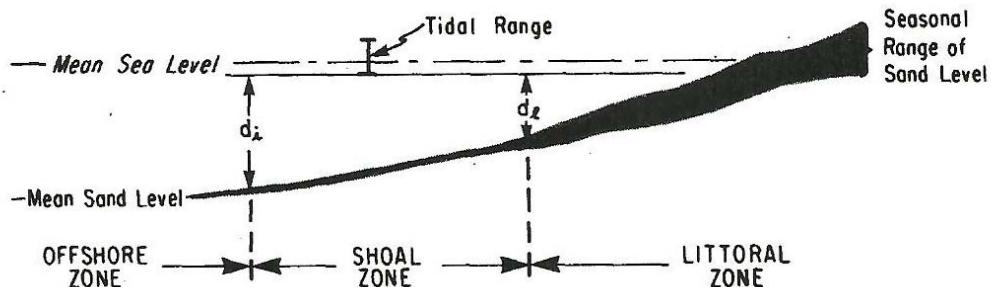


Figure 1. Shore Perpendicular Profile Zonations. (Hallermeier, 1981).

Using Hallermeier's depth limits, Hands and Allison (1991) investigated 11 berms to find a correlation between water depth placement and stability of the berm. The 11 cases were categorized into two types of berms, active and stable.

Active berms are those that show significant movement within the first few months. Stable berms retain most of their original volume and remain at the placement site for years. For the purposes of their study, the authors defined d_i and d_o as Hallermeier's inner limit (HIL) and Hallermeier's outer limit (HOL), respectively. The results showed that in the 11 cases, berms constructed in depths above HIL included only active berms, and depths below HOL included only stable berms. Within the 'buffer zone' or 'shoal zone' (HOL-HIL), active berms were found at depths 50 percent above the HOL, but still below HIL, and stable berms were found at depths below the 50 percent cutoff (Figure 2). Through wave climate study results, the authors also stated that in locations where wave-induced bed disturbances were low, the dredged material failed to move landward, and remained stable. The results showed that the distribution of long-term, wave-induced, near-bed velocities categorized each of the 11 cases into active or stable berms accurately.

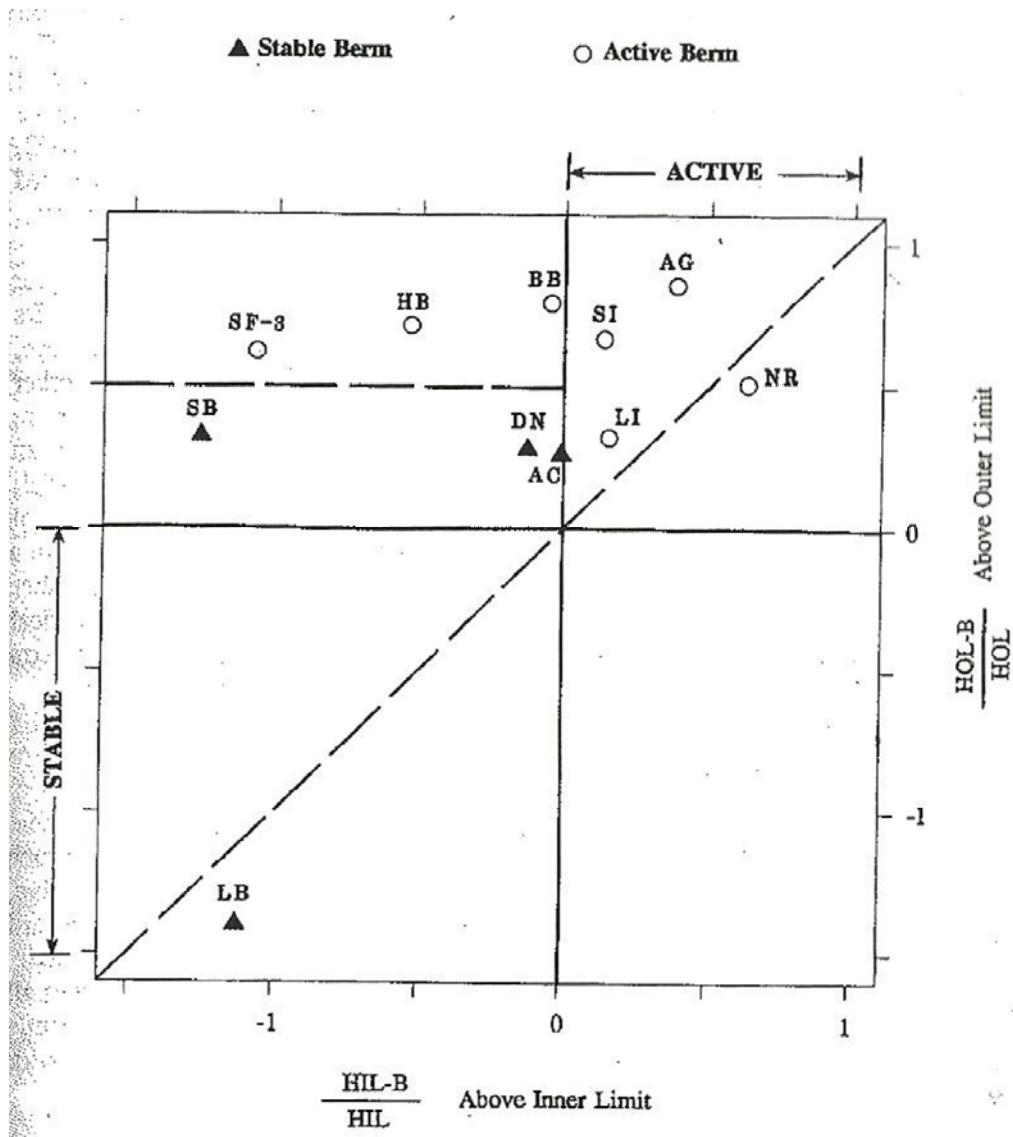


Figure 2. Hands and Allison (1991) Active vs. Stable Berms.

McLellan and Kraus (1991) described artificial berms from a different approach. Feeder berms were defined as those that are meant to enhance adjacent beaches by mitigating erosive wave action and adding material to the littoral system. Stable berms were described as permanent features that are placed to reduce wave energy, and possibly serve as a fish habitat. Design

guidance is given in this study including when to place the berm (mid-summer), where to place the berm (ideally in an undisturbed beach), and how to construct the berm. To construct an active berm, the authors suggest building at the shallowest depth a dredge can safely navigate, making it long enough such that wave energy won't focus to cause erosion at the shoreline, and to create a wider berm that will break more waves. Finally, the study suggests building berms with coarser sands as finer sands were determined to be unsuitable for nearshore berm construction based on an example from Bald Head Island, North Carolina.

Larson and Kraus (1989) created a criterion using the fall speed parameter (Dean, 1973), H_o/wT , where H_o is the offshore wave height, w is the fall speed of the sand and T is the wave period. Kraus (1990) verified the criterion and both studies (Larson and Kraus, 1989; Kraus, 1990) concluded that if H_o/wT is less than 3.2, the beach will tend to accrete. If H_o/wT is greater than 3.2, the beach will tend to erode.

Using an example of a nearshore berm in Silver Strand State Park, California as a guide, Allison and Pollack (1993) evaluated prototype designs for berms by using two numerical models, Regional Coastal Processes WAVE (RCPWAVE) (Ebersole, Cialone, and Prater, 1986) and Numerical Model of Longshore Current (NMLONG) (Kraus and Larson, 1991). RCPWAVE was used to evaluate crest lengths and end slopes on wave conditions, and NMLONG was used evaluate influences of longshore currents on berm widths. The results showed that a berm with an inshore slope of 1 to 25, an offshore slope of 1 to 50,

end slopes of 1 to 125, a crest length of [2000 ft] or greater and a crest width of [200 ft] or greater is the optimum berm design for [-18 ft] of water.

Douglass (1995 and 1996) created a model to illustrate the landward migration of nearshore berms. The assumption behind this model is that the dominant driving force for constructed sand mounds is waves and that wave orbital velocities are asymmetrical. That is, the orbital velocity in the crest (directed onshore) is larger than the orbital velocity in the trough of the wave (directed offshore). The model uses Bailard and Inman's (1981) form of Bagnold's (1963) bed load transport model as a basis for mound movement. Given an estimate of the onshore portion of the wave climate, the expected value of mound movement E , in any give depth h , $E[C(h)]$, can be estimated with C , the convection coefficient as follows (2):

$$E[C(h)] = \iint p(H, T)C(H, T, h)dHdT \quad (2)$$

With a tabular estimate of the joint probability of H and T , this is

$$E[C(h)] = \sum p(H, T)C(H, T, h) \quad (3)$$

where the summation is across all (H, T) bins and $p(H, T)$ is the probability of time that the wave height and period is of that magnitude. When applied to the Silver Strand mound, the model accurately depicted landward migration in that study area. The 1995 model is further developed in the 1996 paper, eventually concluding that, based on the model, doubling the migration rate requires placement in 13-16% shallower depths. Doubling the depth of placement will decrease the rate of migration by a factor of 16 to 32.

Scheffner (1991) created a method to predict the stability of disposal site material. The prediction is based on a site stability simulation using wave, storm surge, and tide data. The model is a hydrodynamic, sediment transport, and bathymetry change model which computes stability over time as a function of waves, currents, bathymetry, and sediment size. The result of the model is a velocity distribution at the site that can be used to calculate spatial distribution of sediment transport. To test the stability model, the study compared its results to the actual results from a mound placed offshore of Dauphin Island, Alabama (the Sand Island Mound), which yielded a general agreement between them. The authors state that the result of this study reinforces the notion that accurate model stability predictions can be obtained if the simulations are based on realistic data. This particular model was ultimately deemed to be a viable technique to providing quantitative predictions of disposal site stability.

Examples of Previous Nearshore Disposal Berms

Construction of submerged berms appears to have begun in the mid-1930s in Santa Barbara, California (Hall, 1953), but interest in this type of nourishment or shore protection has increased in the recent past. This section describes several case studies of underwater berms that have occurred since the early 1970s, many of which employ the previously discussed models and techniques to describe the dynamics of the spoil sites.

Zwamborn, Fromme, and Fitzpatrick (1970) studied an underwater mound placed offshore of Durban, South Africa. The mound was put in over the course

of 4 years, and had still yet to be completed by publication of the Zwamborn et al. study. However, the mound, which was designed to be [2.8 mi] long, [200 ft] wide with side slopes of 1 to 25 and [3900 ft] offshore, was found to protect the beaches in its lee side. It was predicted that once the mound was completed, it would provide protection to all of the beaches by attenuating wave energy, similar to a submerged breakwater. This study also created predictive models for the underwater mound, and found that moveable bed models which were designed in accordance with the shear-settling velocity criterion accurately predicted beach changes in the study area.

Andrassy (1991) and Juhnke, Mitchell and Piszker (1990) monitored the placement of a nearshore berm at Silver Strand State Park located in San Diego, California. The berm was placed in December 1988 using dredged material from the San Diego Harbor. According to the USACE Technical Report by Juhnke, Mitchell and Piszker (1990), in order to assure that the berm would be set in motion by waves, it must be placed above the depth of closure contour, which in this case was the -33 ft MLLW contour. The berm was approximately 1200 ft long, 600 ft wide and had an average relief of 7 ft. Over the course of Andrassy's study, the berm flattened out and migrated onshore. Based on survey data and wave data, Andrassy (1991) concluded that location of the berm in the littoral zone, water depth under the crest of the berm, and wave climate in the site were the key factors in determining whether the berm would move onshore or offshore, assuming compatibility of native and deposited sediments. The Technical Report ultimately concluded that if designed properly, nearshore placement of clean

dredged material can be performed “easily and safely” with the additional benefits of cost savings and benefits to the coastal environment.

Maintenance dredging of Canaveral Harbor in 1992 and 1993 resulted in a nearshore berm disposal in Port Canaveral, Florida, offshore of Cocoa Beach. Bodge (1994) evaluated the performance of the berm using survey and sediment data. The study found that the most rapid onshore movement of the berm happened within days to a few weeks of placement. Initial movement was approximately 100 ft landward over the first 1 to 6 week period. After that, the profile seemed to equilibrate as the rate of onshore migration was less rapid over the next 10 months. Bodge found that the Hands and Allison (1991) criterion was upheld because the portion of the berm located greater than -25 ft depth contour (MLW) showed significantly less rapid migration, while less than the -22.5 ft water depths (MLW) migrated more rapidly and significantly shoreward. This study also found that there was no offshore movement or significant alongshore movement of the material at this site.

Otay (1995) and Work and Otay (1996) performed studies on a nourishment in Perdido Key, Florida in 1989. This nourishment involved both direct beach nourishment and nearshore berm nourishment in approximately [18 ft] water depth. Otay (1995) monitored the nourishment through topographic and bathymetric surveys, wave, current and tide measurements, sediment sampling, meteorological data acquisition, and oblique photography. Using this data, it was concluded that there were no measureable volumetric changes in the berm, and that the berm did provide some amount of protection to the leeward beaches.

Work and Otay (1996) went on to say that the berm was stable and did not migrate, rather the berm smoothed out. The authors concluded that the berm influenced breaking wave climate by redistributing the wave energy alongshore. In 2000, Browder and Dean compared the monitoring results at Perdido Key with the predictive models of the project. They found that after 8 years of monitoring, the sand placed during nourishment project retained 56% of the original volume placed within the project area. The beach, which was initially constructed to be [440 ft] wide on average, was still [170 ft] wider than the pre-project conditions, and that approximately 41% of the originally placed dry planform area remained as of July 1998. Over the course of this study, the submerged berm had shown little change over the project life, with only slight onshore migration.

Based on Hands and Allison (1991) classification of a berm placed in Newport Beach, California in 1992, Mesa (1996) stated that the berm could be considered both stable and active. Based on near bed velocities, the berm would be considered stable, however, based on Hallermeier limits the berm would fall in the 'buffer zone' and Hands and Allison (1991) stated that berms that are 50% above the outer limit are considered active. The Newport Beach berm would then be considered active, but the author suggested that it may be considered 'weakly active' based on the fact that its position was only slightly greater than the 50% outer limit. Overall the berm was migrating shoreward at a rate of about 100 ft/year, but there was little to no indication that the berm was moving alongshore. Additionally, the berm seemed to improve the surfing conditions in the area.

Aidala, Burke, and McLellan (1996) investigated the hydrodynamic forces and evolution of a nearshore berm at South Padre Island, Texas. The berm was constructed off the coast in January 1989. It was placed 3,000 to 4,000 ft offshore along the 26 ft depth contour. Bathymetry and hydrodynamic studies were performed during 4 different monitoring periods (01/04/1989, 01/04/1989-03/09/1989, 03/10/1989-06/19/1989, and 06/19/1989-05/14/1990). During the first study period, the berm moved onshore approximately [200 ft]. The second study period saw no movement, and during the third study period the berm moved offshore [150 ft]. It was concluded that the hydrodynamic forces driving the evolution of the berm were wave induced shear stress and bottom currents. The authors stated that movement and erosion are influenced by the relation between shear stress, threshold velocity and bottom current velocity, and that when shear stress, produced by orbital velocities, exceeds threshold velocities; sediment is dislodged and initiates the berm evolution process.

Johnson and Work (2005) investigated a berm placed near the Brunswick Harbor Entrance Channel in Georgia, in an attempt to nourish downdrift Jekyll Island. The study uses four methods to predict sediment transport rates including the flux computed directly from the measurements; the Shield's Nielson method, which relates dimensionless sediment transport rate to dimensionless excess shear stress; Van Rijn's method, which accounts for both bed load and suspended load, but not waves; and Soulsby's method, which approximates bed load transport in a combined wave-current environment. The flux is computed using

$$q_{ss} = \int_0^h c(z)u(z)dz \quad (4)$$

where, q_{ss} is the suspended transport rate, $c(z)$ is the mean concentration profile, $u(z)$ is the mean velocity profile and h is the mean water depth. The Shields/Nielsen method uses the equation

$$\Phi_B = 12(\Theta - \Theta_c)\sqrt{\Theta} \quad (5)$$

where the dimensionless shear stress is given by:

$$\Theta = \frac{\tau}{(\gamma_s - \gamma)d} \quad (6)$$

and the dimensionless sediment transport rate is given by:

$$\Phi_B = \frac{Q_B}{d\sqrt{(s-1)gd}} \quad (7)$$

Where Θ_c is the critical dimensionless shear stress, τ is the shear stress on the bed, γ_s is the specific weight of the sediment, γ is the specific weight of water, d is the diameter of the particle, Q_B is the bed load, g is the acceleration due to gravity, and s is the sediment specific gravity. The Van Rijn method uses a transport method for riverine environments as follows:

$$q_b = 0.005\bar{U}h \left[\frac{\bar{U} - \bar{U}_{cr}}{[(s-1)gd_{50}]^{1/2}} \right]^{2.4} \left(\frac{d_{50}}{h} \right)^{1.2} \quad (8)$$

and

$$q_s = 0.012\bar{U}h \left[\frac{\bar{U} - \bar{U}_{cr}}{[(s-1)gd_{50}]^2} \right]^{2.4} \left(\frac{d_{50}}{h} \right) (D_*)^{-0.6} \quad (9)$$

and

$$q_t = q_b + q_s \quad (10)$$

Where q_t is the total load transport rate, q_b is the bed load transport rate, q_s is the suspended load transport rate, U is the depth averaged current, U_{cr} is the critical

velocity required for sediment transport, d_{50} is the sediment diameter for which 50% is finer by weight, and h is water depth. And finally Soulsby's method uses

$$q_{bx} = \Phi_x [g(s - 1)d_{50}^3]^{1/2} \quad (11)$$

where,

$$\Phi_{x1} = 12\theta_m^{1/2}(\theta_m - \theta_{cr}) \quad (12)$$

and,

$$\Phi_{x2} = 12(0.95 + 0.19 \cos 2\phi)\theta_w^{1/2}\theta_m \quad (13)$$

where Φ_x is the maximum of Φ_{x1} and Φ_{x2} , q_{bx} is the mean volumetric bed load transport rate per unit width, θ_m is the mean Shields parameter over a wave cycle, θ_w is the amplitude of oscillatory component of θ due to waves, θ_{max} is the maximum Shields parameter from combined wave-current stresses, θ_{cr} is the critical Shields parameter for initiation of motion, and ϕ is the angle between current direction and direction of wave travel. These four methods only predict the gross quantity of sand movement, but not the direction, so sediment transport roses were constructed to indicate both the direction and rate of sediment transport. The study found that the sand largely followed the channel axis, but with an onshore bias, which meant that some of the material may make it to Jekyll Island, but it is not directed that way when it initially leaves the mound.

From the previous research on design guidance and examples of berm nourishments, it is clear to see that some important factors in designing berms are its height, width, length, depth of placement, and grain size. Also important are the hydrodynamics and regional morphology in the area to understand the migration of the berm. Several predictive models have been created to gain

better insight into the movement of nearshore berms post construction. When designed properly, many of the cases showed that the berm could act as a submerged breakwater by attenuating high wave energy and protecting the leeward beaches from erosion, emphasizing that this type of nourishment is a favorable option for disposal of dredged material.

STUDY AREA

Matanzas Pass, located along Fort Myers Beach at the northern tip of Estero Island in west-central Florida, is a federally maintained navigation channel, which is used for fishing, recreation, and as a primary access for the U.S. Coast Guard. Figure 3 shows a map of Estero Island including Fort Myers Beach, Matanzas Pass, and Bowditch Point. The channel has been dredged in 1986, 1996, and 2001, with the dredged sand being placed along the adjacent beaches, as well as in the nearshore zone. Since the dredging in 2001, Matanzas Pass had completely shoaled, and the tip of Estero Island, also called Bowditch Point, was expanding across the channel. The shoaled channel posed a safety hazard with boaters, as well as interfered with the U.S. Coast Guard's ability to respond to emergencies, which prompted a new dredging cycle in 2009 (Florida Department of Environmental Protection, 2009). This thesis is part of a report for the U.S. Army Corps of Engineers (USACE) that funded this research, and therefore uses English units as opposed to metric units. Appendix A shows the conversion factor from meters to feet used in this study.

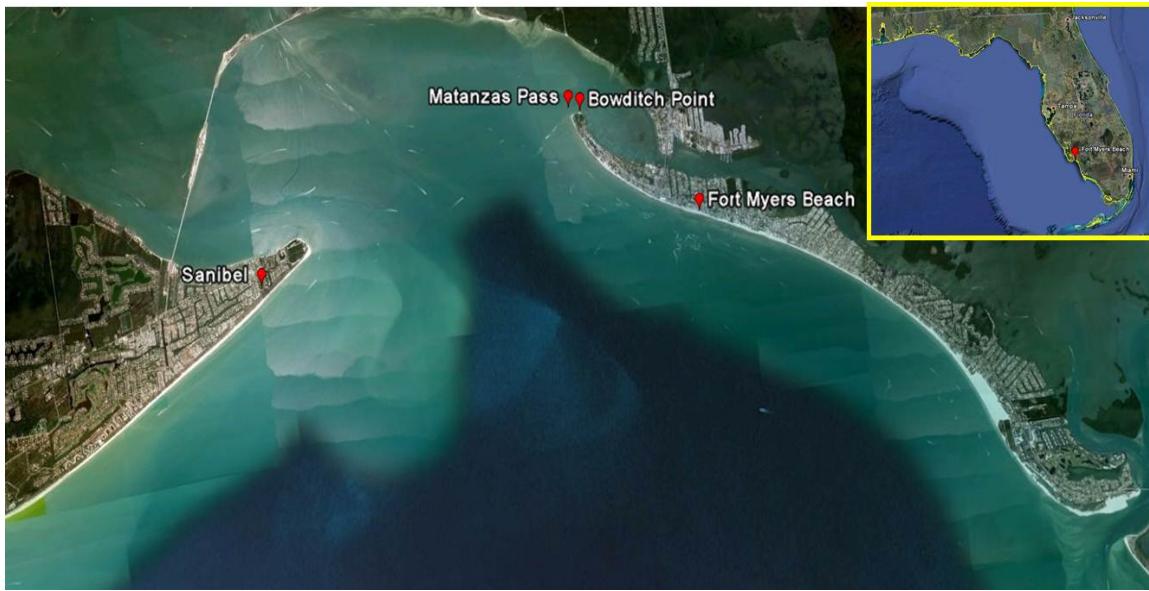


Figure 3. Location of Fort Myers Beach. Matanzas Pass and Bowditch Point are located at the north end of Estero Island, Florida.

Berm Construction

The Fort Myers Beach berm was constructed using material dredged from Matanzas Pass and Bowditch Point. The dredging project took place between April and October 2009. A hydraulic dredge was used and the material was placed in the form of a nearshore berm, 1.5 miles southeast of the dredging area. Figure 4 shows the initial design location of the berm. The berm was designed to be placed 600 ft offshore, in 6 ft water depth (NAVD88). Initially, the berm was designed to be 6,000 ft long, 400 ft wide and 3 ft high, with slopes of 1 to 20. A total of 229,313 cu. yd was placed in the nearshore. The nearshore berm was made up of both silt and sand fractions, with an average silt concentration of 7.71%, and a maximum concentration of 16.15% (Florida Department of Environmental Protection, 2009).

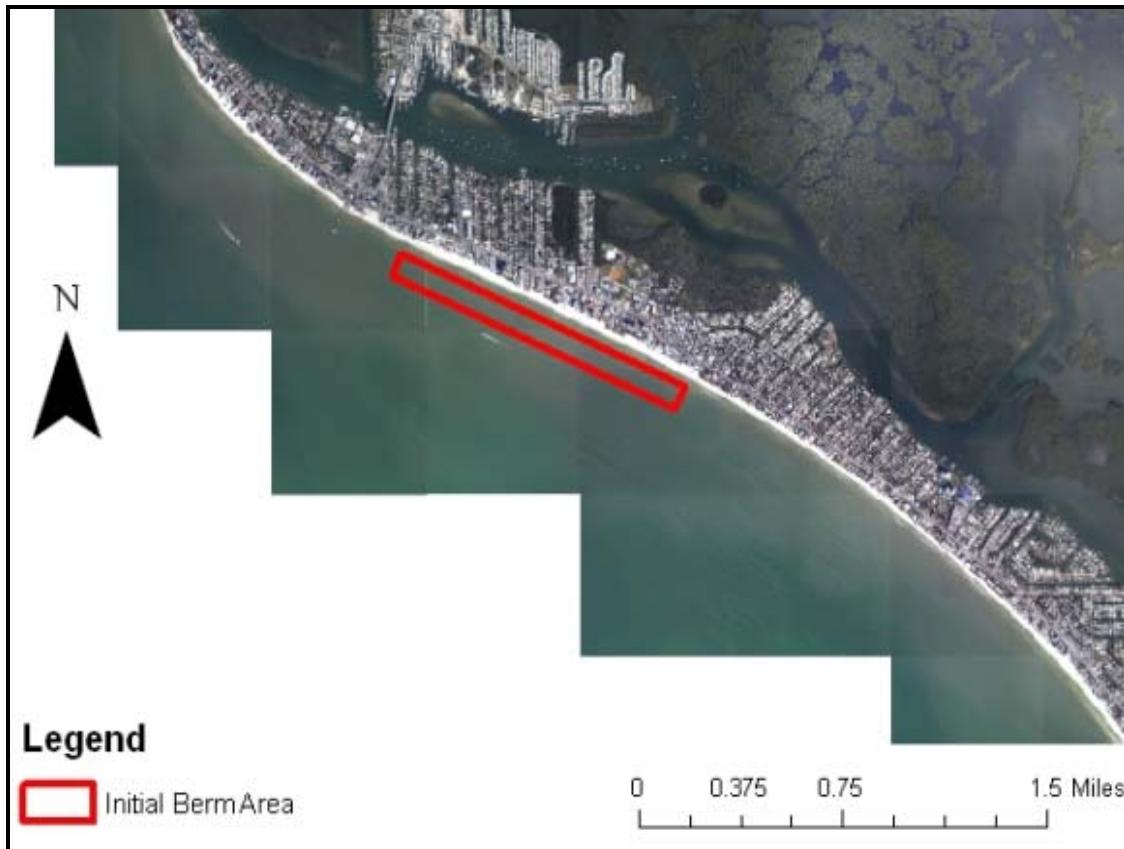


Figure 4. Designed Berm Placement Location.

An 18" suction cutter dredge was used to dredge the material from Matanzas Pass. The dredging took place in three stages. In Stage 1, shoaled upland material in the northeastern tip of Estero Island, located within the previous navigation channel, was dredged. Stages 2 and 3 of dredging included the shoaled channel offshore and the bay side of the island, respectively. Fill began in the northern portion of the project area and moved south. Although the berm was intended to be placed uniformly throughout the project area, considerable longshore variation occurred during construction due to construction feasibility and methodology, although exact details of placement

methodology are unknown. As a result, several gaps of less than 50 ft wide were left after construction.

Meteorological and Oceanographic Conditions

Nearshore waves in the area are mostly generated by local winds, except during rare extreme events such as tropical storms. Table 1 summarizes the post construction wind conditions during the study period from October 2009 until October 2010, including only on-shore directed winds (NOAA station 8725110, approximately 25 miles south of Estero Island). Onshore wind, averaging slightly less than 13 ft/s (9 mph), occurs 32% of the time. The relatively stronger winds approach from the southeast (130-175 degrees) and from the northwest (266-310 degrees). These winds are highly oblique compared to the shoreline orientation (130-310 degree strike). The overall intensities and occurrences of the southeast and northwest winds, which drive longshore sediment transport in opposite directions, are statistically similar (Table 1). However, the study area may be sheltered by Sanibel to the northwest (refer to Figure 3), and therefore the winds recorded from the northwest may be stronger than the actual winds that occur at Fort Myers Beach, as the station is located 25 miles south of the study area in an region with no potential sheltering. No major tropical storm occurred during the first year after construction. The study area is influenced by a mixed tide regime. Spring tides tend to be diurnal with a range of nearly 4 ft, while neap tides are semi-diurnal ranging about 2.0 to 2.5 ft (Figure 5).

Table 1. Statistical Wind Conditions During the First Year After Berm Construction.

General Direction	Southeast	South-Southwest	West	Northwest
Wind Speed	130-175 deg.	176-220 deg.	221-265 deg.	266-310 deg.
% < 13 ft/s	61.1	95.1	69.9	55.4
% 13-23 ft/s	28.7	4.0	29.3	35.5
% 23-33 ft/s	8.9	0.9	0.5	7.3
% > 33 ft/s	1.3	0.0	0.3	1.8
Avg. Speed (ft/s)	12.5	4.8	10.8	13.4
% of Total Wind	10.8	4.9	7.1	8.9

*October 2009 to October 2010 (From NOAA station 8725110)

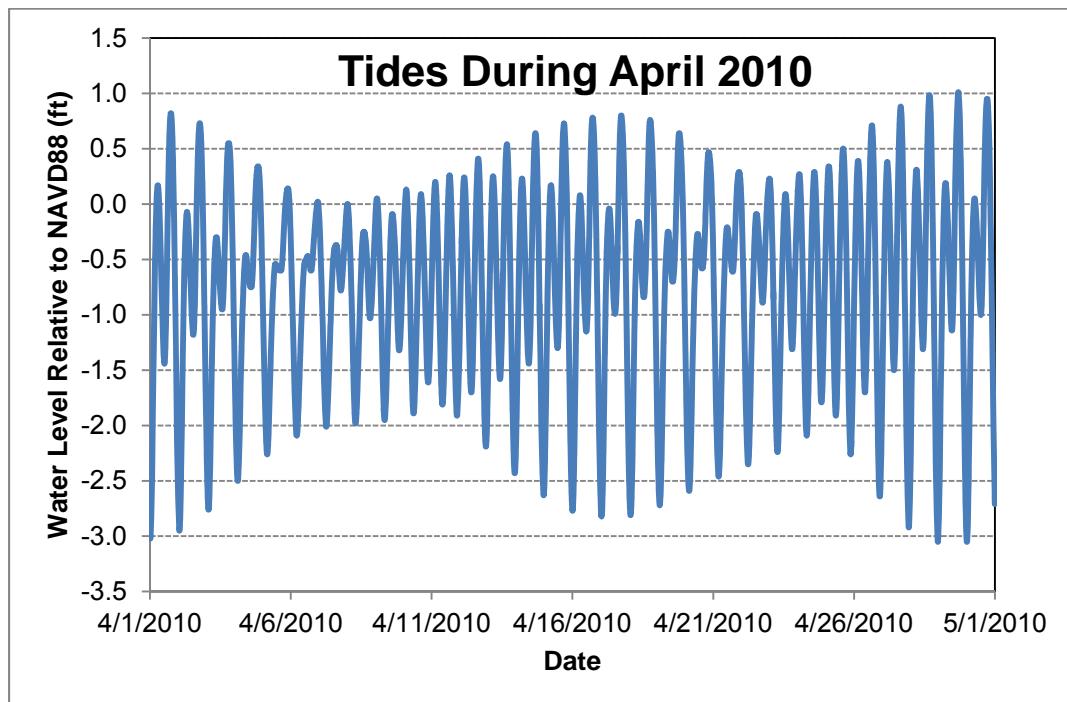


Figure 5. Measured Tides during April 2010. Data collected from the NOAA Naples Station (8725110), approximately 20 miles south of the study area.

METHODOLOGY

First year morphological changes and sediment characteristics of the Fort Myers Beach berm, Florida were characterized using beach profile surveys, shoreline surveys, and surface sediment samples taken within the study area.

Field Methods

A pre-construction survey of the area was conducted by the Jacksonville District of the USACE in May 2009. An initial post-construction survey was also conducted by the Jacksonville District of the USACE in October 2009. Both of the surveys included hydrographic and topographic surveys. According to the surveyor's reports, hydrographic survey data were collected using an Odom transducer and fathometer. Horizontal positioning was given using a real time kinematic global positioning system (RTK GPS) with real time tide corrections. Horizontal and tide values were checked daily with a tide staff at the boat launch. Topographic surveys were completed using an RTK GPS with automated data collection.

Beginning April 2010, surveys were conducted by the University of South Florida Coastal Research Laboratory (USF CRL) in the artificial berm area as well as control areas approximately 1 mile northwest and southeast of the berm, respectively (Figure 6). The project area was resurveyed in October 2010.

Surface sediment samples were also taken across 11 of the beach profile transects (Figure 7).

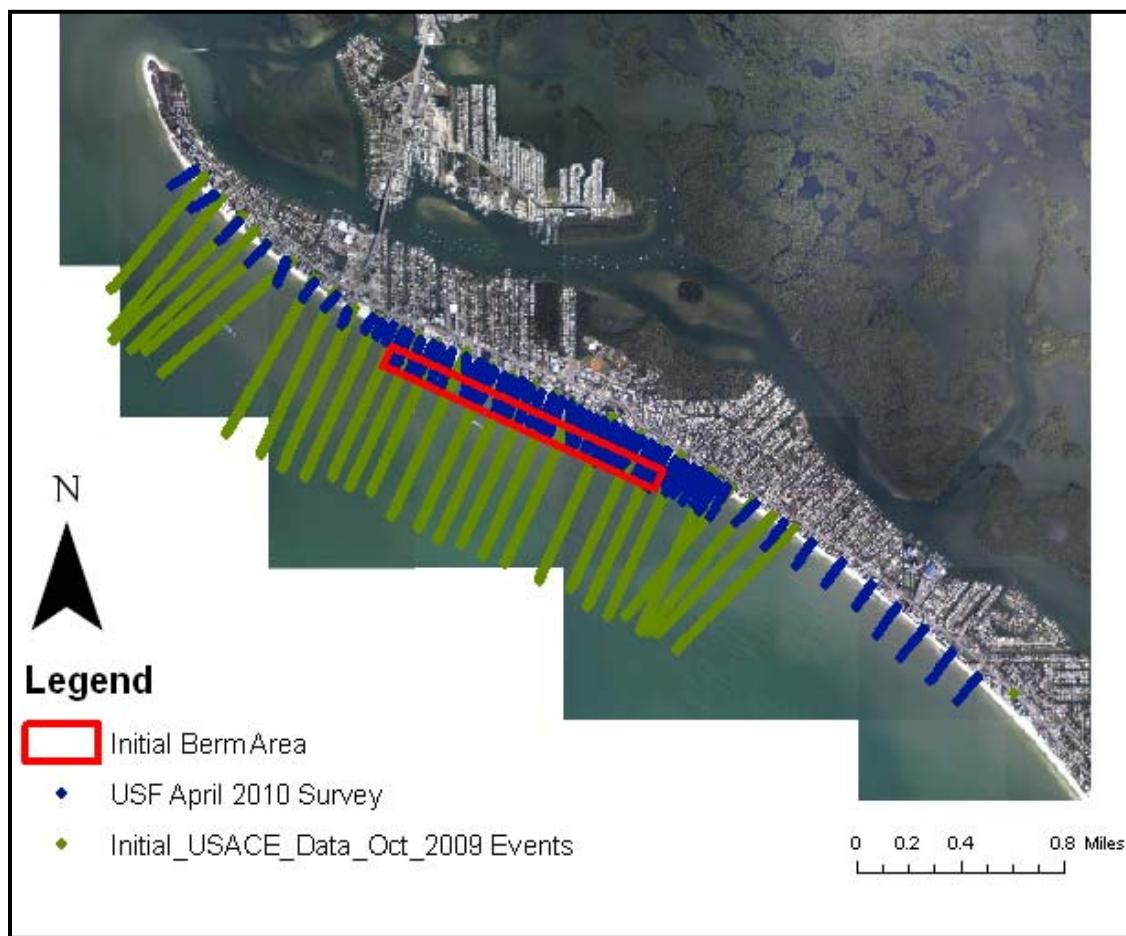


Figure 6. USACE and USF Survey Line Locations.

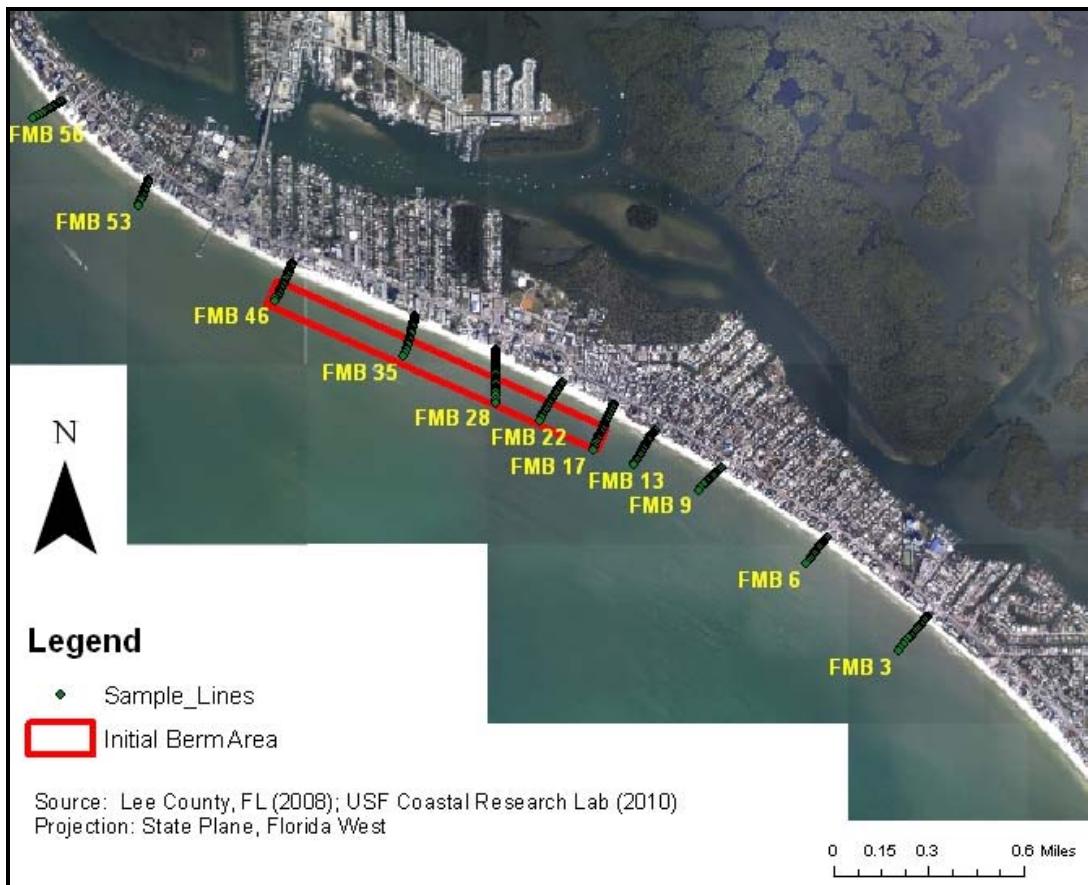


Figure 7. Locations of Sediment Sampling Transects.

USF CRL beach profiles were established by creating benchmarks using a RTK GPS (Figure 8). Typically, two stakes were placed, one as a monument and one as an instrument location, and their coordinates recorded so that the line could be reoccupied and surveyed again in the future. Lines in the control area were spaced in approximately 600 ft intervals, while lines over the berm were placed approximately 150 ft apart to allow for more dense data coverage in that area. In total, 57 profiles were established and surveyed using an electronic total station and prism following standard level and transit procedures beginning at the benchmark and extending to approximately 8 ft water depth (NAVD 88).

Shoreline survey data was collected using RTK GPS. A four wheel all-terrain vehicle was used to tow a small cart carrying the RTK GPS to reduce inaccurate elevation data due to suspension on the vehicle (Figure 9). Shore parallel lines at approximately the vegetation line, mid back beach, berm crest, mid-tide line, and foreshore were surveyed. Shoreline surveys extended approximately 1 mile northwest and southeast of the berm project area.



Figure 8. Temporary Benchmark Establishment. At each line, two stakes were placed so that the same line could be reoccupied and surveyed again.



Figure 9. Shoreline Survey Using an ATV and a Cart. A small cart was towed by an ATV for shoreline surveys.

Surface sediment samples were taken across 11 beach profile transects: 2 northwest of the berm, 5 across the berm, and 4 southeast of the berm. Typically, 9 samples were collected in the control areas, and 11 samples were collected in the berm area. In the control areas, surface sediment samples were taken at approximately the toe of the dune (where present), backbeach, high tide line, mean sea level, low tide line, 2 ft water depth, 4 ft water depth, 6 ft water depth, and 8 ft water depth relative to NAVD88. In the berm area, surface sediment samples were taken at approximately the toe of the dune (where

present), backbeach, high tide line, mean seal level, low tide line, roughly in the middle between the berm and the shoreline, landward toe of the berm, midway up the landward slope of the berm, top of the berm, and seaward approximately every 100 ft until about 8 ft water depth, and at 8 ft water depth relative to NAVD88. A total of 104 samples were collected.

Laboratory Methods and Data Analysis

Beach profile data were processed using the U.S. Army Corps of Engineers Coastal Hydraulics Laboratory developed program, Regional Morphology and Analysis Package (RMAP) and Microsoft Excel. Using the State Plane Florida West northing and easting coordinates that were collected during the surveys, distances were calculated from the monument of the survey line being processed. With the calculated distances and their associated recorded elevations, beach profiles were created. Profiles were analyzed to find location of berm crest, elevation of berm crest, berm height, rate and direction of bar migration. Berm crest is defined as the highest survey point on the berm portion of the survey, Berm height is the difference between the berm crest elevation and the landward trough elevation. For each survey within the berm project area, rate and direction of berm migration was calculated by finding the difference between the distances to the berm crest between consecutive surveys. Figure 10 is an example of a beach profile that was analyzed for this study.

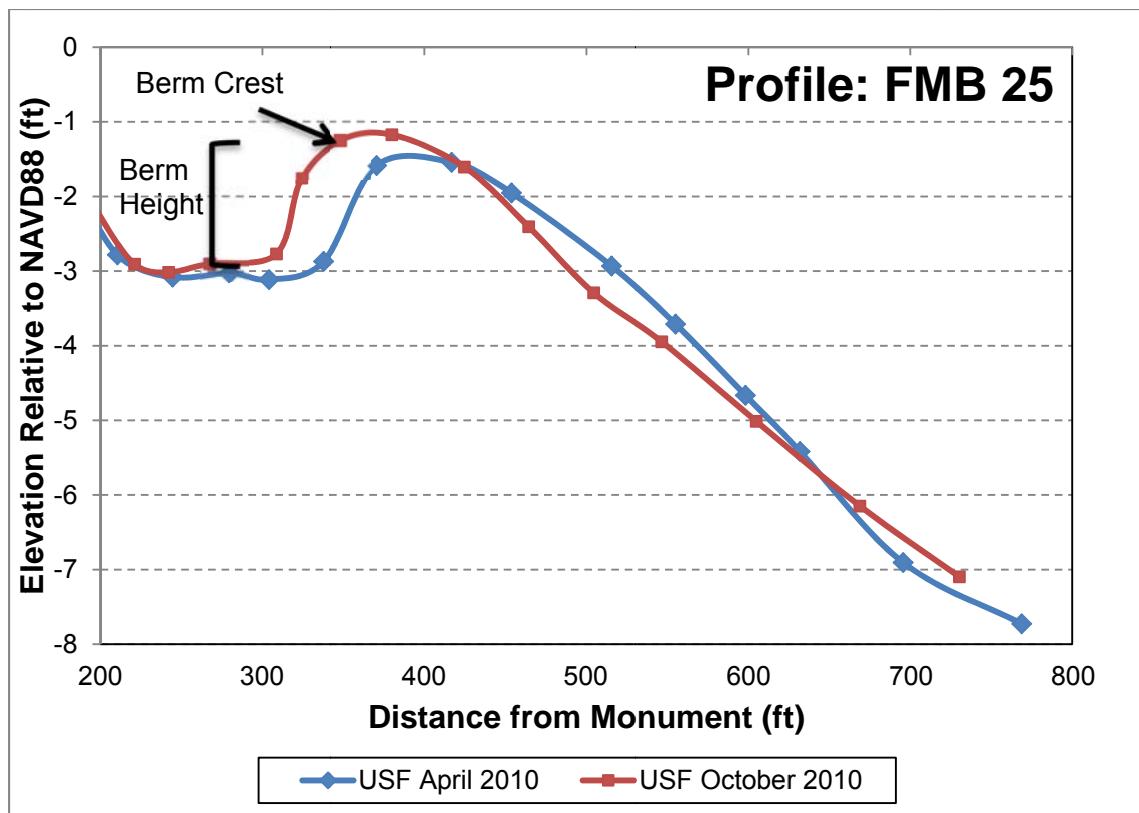


Figure 10. An Example of a Beach Profile. This graph is focused on the berm portion of profile FMB 25. The berm height is defined as the distance between the landward trough and the berm crest. The migration rate is defined as the difference between the distance to the berm crest between consecutive surveys.

Initial volume of the bar was calculated using the pre-construction USACE data from May 2009 and the post-construction data from October 2009. The results were compared with the recorded volume from the dredging. The bar was defined as the volume in the post-construction profile above the pre-construction profile, from the deepest trough point to the depth of closure (DOC). Changes in overall profile volume between the USF CRL April 2010 and October 2010 profiles were also calculated, as well as changes in the nearshore and bar

areas. By comparing volume changes across the profile, a better understanding of sediment transport through the project area could be gained. Specifically, information on whether or not the area was dominated by cross-shore or longshore sediment transport, or a combination of the two was analyzed.

All profiles across the berm were interpolated to mean higher high water (MHHW, 0.58 ft above NAVD88) and plotted together to observe longshore variations over the berm relative to MHHW, as discussed later in the following sections. Average profiles were created for pre-construction and post-construction data. Because the same data points were not taken for each survey, the profiles were interpolated to every 10 feet for profile averaging. This procedure was employed for the profiles northwest of the berm, within the berm, and southeast of the berm. The standard deviation was also calculated and added to and subtracted from the average to find a profile envelope representative of each of the three sections in the study area. Average profiles were created to have a consistent profile with which to compare all profiles in the corresponding section.

Surface sediment samples were analyzed using standard sieves. A 4 phi (0.063 mm) wet sieve was used to separate mud size sediment from coarser sediment. Coarser sediment was then sieved using a Rototap. Grain size and sorting of each sample was calculated using the moment method (Krumbein and Pettijohn, 1938), which gives a weighted average of the grain size as well as a standard deviation that relates to the sorting of the sample. Both wet and dry color descriptions were recorded using the Munsell color chart. The sand and

gravel fractions were then burned with hydrochloric acid to analyze carbonate concentrations of each of the samples. The carbonate grains are mostly shell debris. Table 2 provides an example summary of the sedimentological characteristics across a beach profile (refer to Appendix B for all grain size and color analysis tables).

Table 2. Example Grain Size and Color Analysis Data from FMB 56.

FMB 56-1	% Gravel	0.20	$x\phi =$	2.70	$\sigma\phi =$	0.50
	% Sand	99.66	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.14	Color:			
	% Carbonates	2.48	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 56-2	% Gravel	0.29	$x\phi =$	2.64	$\sigma\phi =$	0.56
	% Sand	99.52	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.19	Color:			
	% Carbonates	3.03	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 56-3	% Gravel	0.19	$x\phi =$	2.74	$\sigma\phi =$	0.44
	% Sand	99.68	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.13	Color:			
	% Carbonates	3.40	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 56-4	% Gravel	0.98	$x\phi =$	2.38	$\sigma\phi =$	0.79
	% Sand	98.80	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.22	Color:			
	% Carbonates	5.46	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 56-5	% Gravel	0.79	$x\phi =$	2.84	$\sigma\phi =$	0.59
	% Sand	98.95	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.26	Color:			
	% Carbonates	2.02	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 56-6	% Gravel	1.46	$x\phi =$	2.90	$\sigma\phi =$	0.77
	% Sand	98.08	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.45	Color:			
	% Carbonates	3.18	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 56-7	% Gravel	0.03	$x\phi =$	2.94	$\sigma\phi =$	0.47
	% Sand	99.00	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.97	Color:			
	% Carbonates	1.42	Wet:	5Y 6/2	Dry:	5Y 8/2

This profile is a control profile located northwest of the berm project area.

Percentages of gravel, sand, mud, and carbonates are recorded. $x\phi$ and $\sigma\phi$ are the mean grain size and sorting of the sample, respectively. The wet and dry sample colors were determined using the Munsell Color Chart. Samples 1, 2, and 3 were located on the dry beach, sample 4 in the swash, and samples 5, 6, and 7 were taken at approximately 1 ft, 2 ft, and 6 ft water depth (relative to NAVD88).

RESULTS AND DISCUSSION

Sedimentological Characteristics of the Artificial Berm

The 104 surface sediment samples, including 61 samples from the control area and 43 samples (refer to Figure 7) from the artificial berm were analyzed using standard sieves. The following section discusses of the results of the sediment analysis, including mud content, carbonate content, and grain size distribution across the profiles southeast of the berm, over the berm, and northwest of the berm.

Cross-shore Grain Size Distributions

Based on the seven vibracores and one grab sample collected at the tip of Bowditch Point, the mean grain size of the dredge material was determined to be approximately 2.6 phi (fine sand), with a sorting value of 0.65 phi (moderately well sorted). The following discusses grain size distribution across profiles in the control area southeast of the berm, within the berm, and the control area northwest of the berm (for all grain size distribution figures, refer to Appendix C).

Control Area Southeast of Berm

Generally, along the profiles southeast of the berm, the dry beach and intertidal zone contain mostly well-sorted fine sand. The swash zone had the

coarsest sediment and was composed of poorly sorted medium shelly sand, and the nearshore (breaker zone) area contained moderately sorted very fine sand, with an increase in mud content toward offshore. Figure 11 shows the grain size distribution across the sample profiles in the control area southeast of the berm.

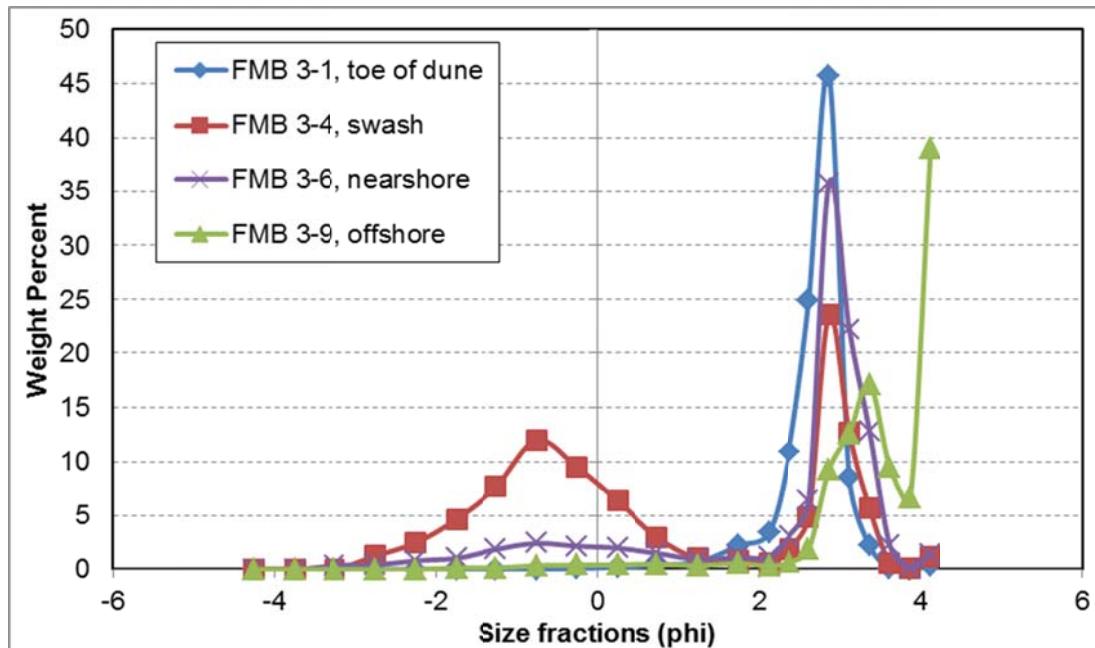


Figure 11. Grain Size Distribution of a Typical Sample Profile Southeast of the Artificial Berm Area. The samples shown are located at the toe of the dune (FMB 3-1), swash zone (FMB 3-4), nearshore (FMB 3-6) and offshore (FMB 3-9).

Berm Project Area

Similar to the control area southeast of the berm, the dry beach and intertidal zone contained mostly well sorted fine sand, and the swash zone had the coarsest sediment with a high content of shell debris. The trough landward of the berm was generally well sorted fine sand. Similar to the swash zone, the

sediment at the landward toe of the berm was also coarse with high content of shell debris. The top of the berm was characterized by moderately sorted fine sand. The sediment along the seaward slope of the berm and offshore was moderately to well sorted fine sand. Figure 12 shows a typical grain size distribution of a sample profile within the berm project area.

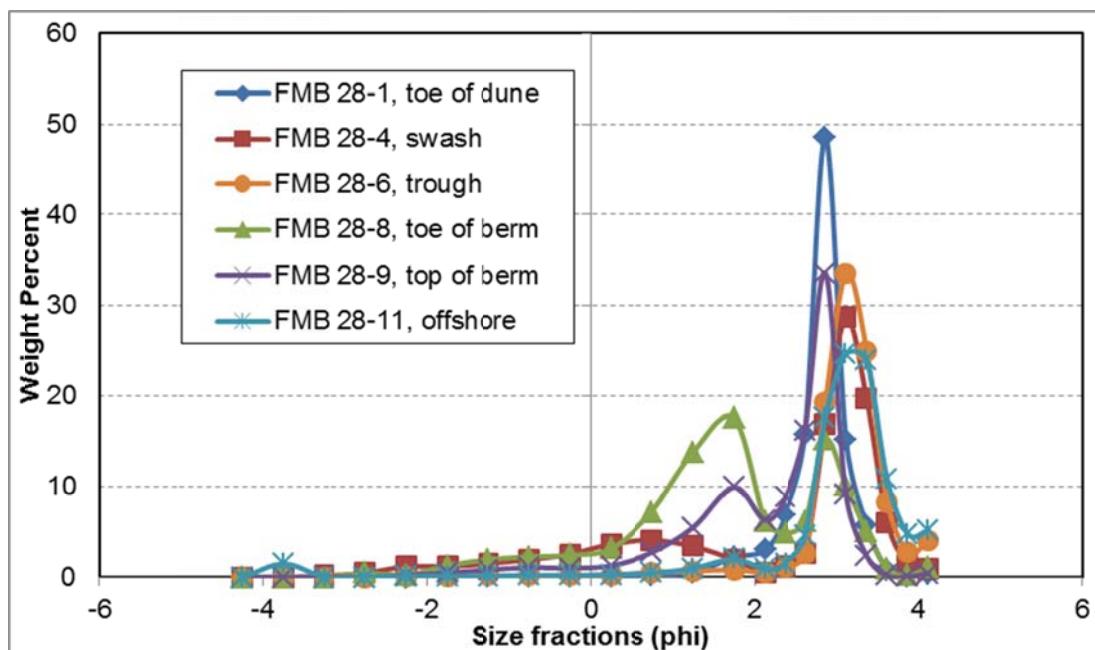


Figure 12. Grain Size Distribution of a Typical Sample Profile Within the Artificial Berm Area. The samples shown are located at the toe of the dune (FMB 28-1), swash zone (FMB 28-4), trough landward of the berm (FMB 28-6), toe of the berm (FMB 28-8), top of the berm (FMB 28-9), and offshore (FMB 28-11)

Control Area Northwest of Berm

The control area northwest of the berm generally contained fine to very fine, moderately well sorted to well sorted sand across the entire profile. Figure

13 is an example of a typical grain size distribution of a sample profile in this area. Overall, compared to the sediments to the south, the content of shell debris was less.

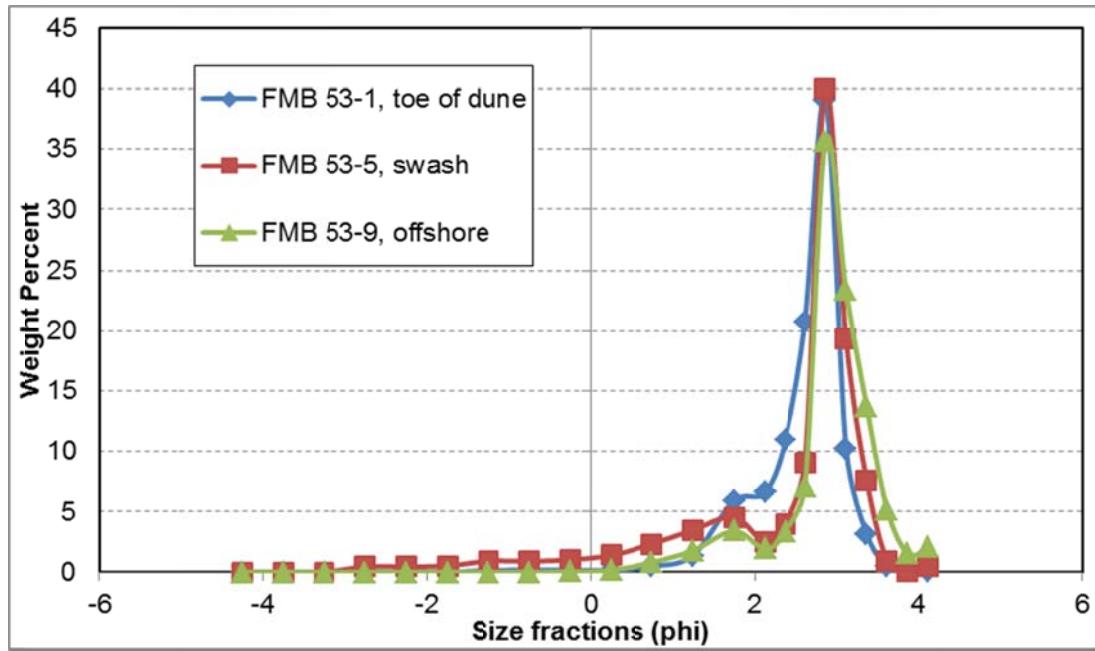


Figure 13. Grain Size Distribution of a Typical Sample Profile Northwest of the Artificial Berm Area. The samples shown are located at the toe of the dune (FMB 53-1), swash zone (FMB 53-5) and offshore (FMB 53-9).

Mud Content

Mud content and its spatial distribution are typically important concerns for berm nourishments. According to the Joint Coastal Permit for the Matanzas Pass Channel Restoration and Maintenance Dredging project (2009), one pre-dredging hand sample and seven vibracores were collected by U.S. Army Corps of Engineers. The composite silt content of the entire volume of the dredge cut

was 7.71%. This is within the 10% maximum silt content allowed for beach placement of sand according to Rule 62B-41.007 (2) (k) from the Florida Department of Environmental Protection, however, five of the vibracores contained more than the allowable maximum. The range of silt content in these vibracores was 9.94% to 16.15%, which is within the 20% maximum silt content allowed for nearshore placement. In addition, several layers within the cores contained silt contents higher than the allowable maximum for beach placement, and due to the type of dredging and placement, it was not expected for the layers to mix to create uniform 7.71% silt content. It was expected that longshore sediment transport to the north is the cause of shoaling within Matanzas Pass, therefore, the material dredged from the pass should be similar to that already on the beach.

Control Area Southeast of Berm

A seaward increasing trend of mud content was measured at most of the profiles. Figures 14 and 15 show representative sample lines located southeast of the berm, with percentage of mud indicated at each sample location. Little mud (mostly less than 1%) was found on the dry beach. Some mud (mostly less than 4%) was found between mean sea level and about 4 ft water depth. Significant mud contents of up to 40% were found in the surface sediment seaward of the 4 ft contour. Considerable variations of mud content are measured in the offshore area (Figures 14 and 15).

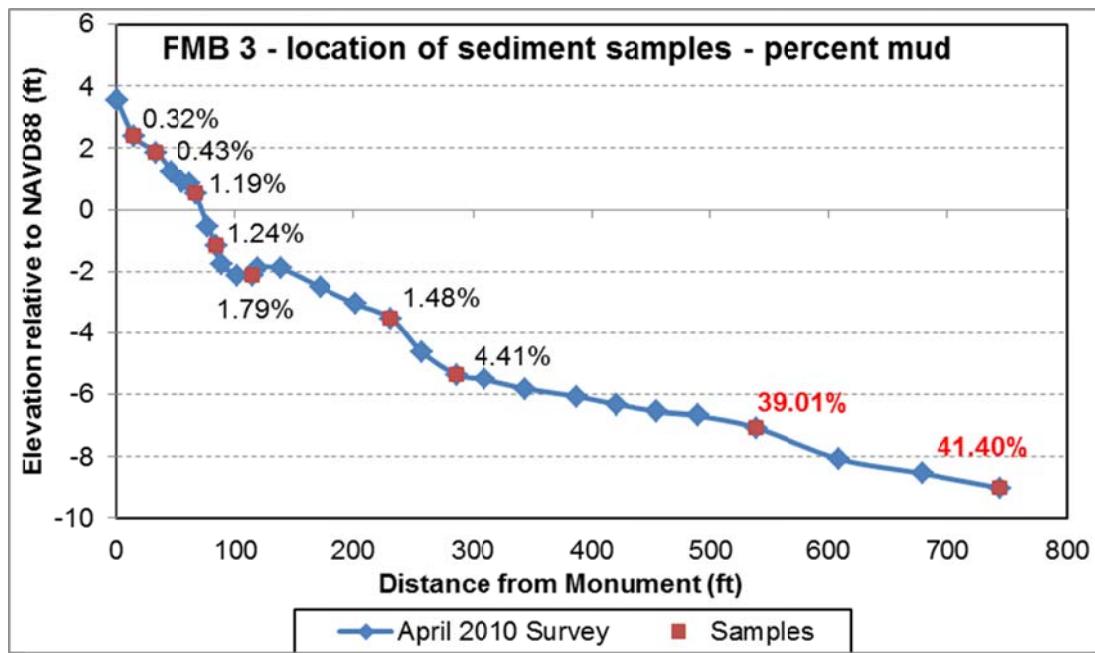


Figure 14. Beach Profile of FMB 3 with Sediment Sample Locations and Mud Percentages.

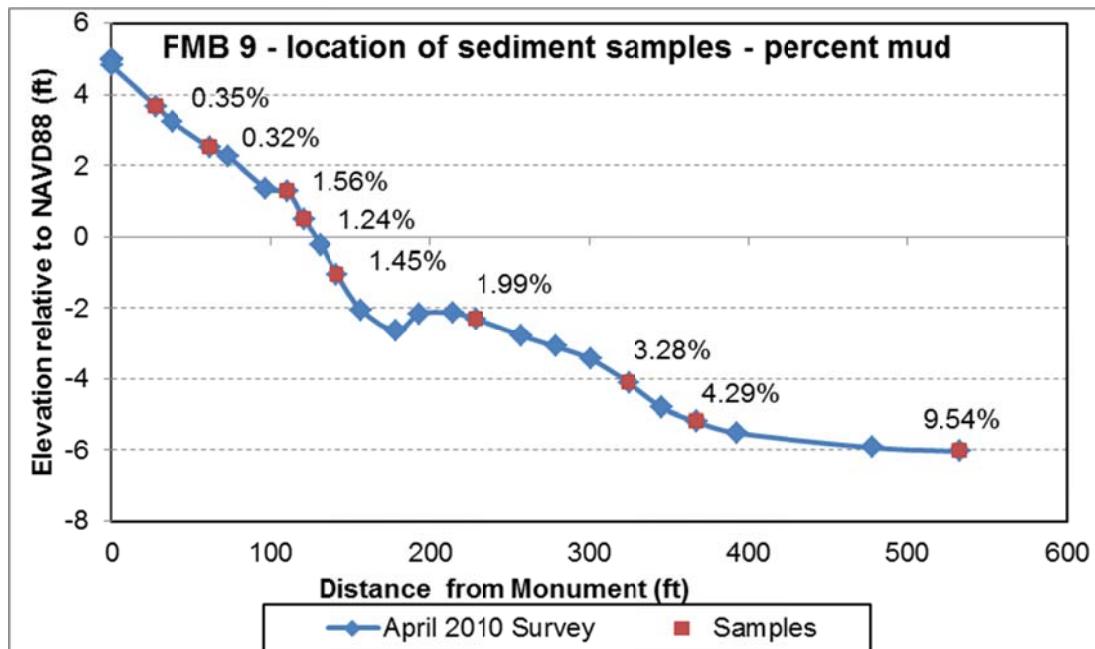


Figure 15. Beach Profile of FMB 9 with Sediment Sample Locations and Mud Percentages.

Berm Project area

Compared to the sample lines southeast of the berm, the samples within the berm area were much less muddy in the offshore region, mostly less than 5% as compared to as high as 40%. Relatively high mud content was observed in the trough between the berm and the shoreline along some of the profiles.

Figures 16 and 17 show the percentage of mud indicated at each sample of representative profiles within the artificial berm area. Generally, less than 2% mud was found on the beach above mean sea level. Less than 3% mud was found on the surface of the berm. The highest mud content was found in the trough landward of the berm, ranging 1 to 4%, with an extreme case at FMB 22, where a patch of mud deposits occurred, (Figure 16) with mud content of 41%. Seaward of the berm the sediment samples contained up to 4% mud.

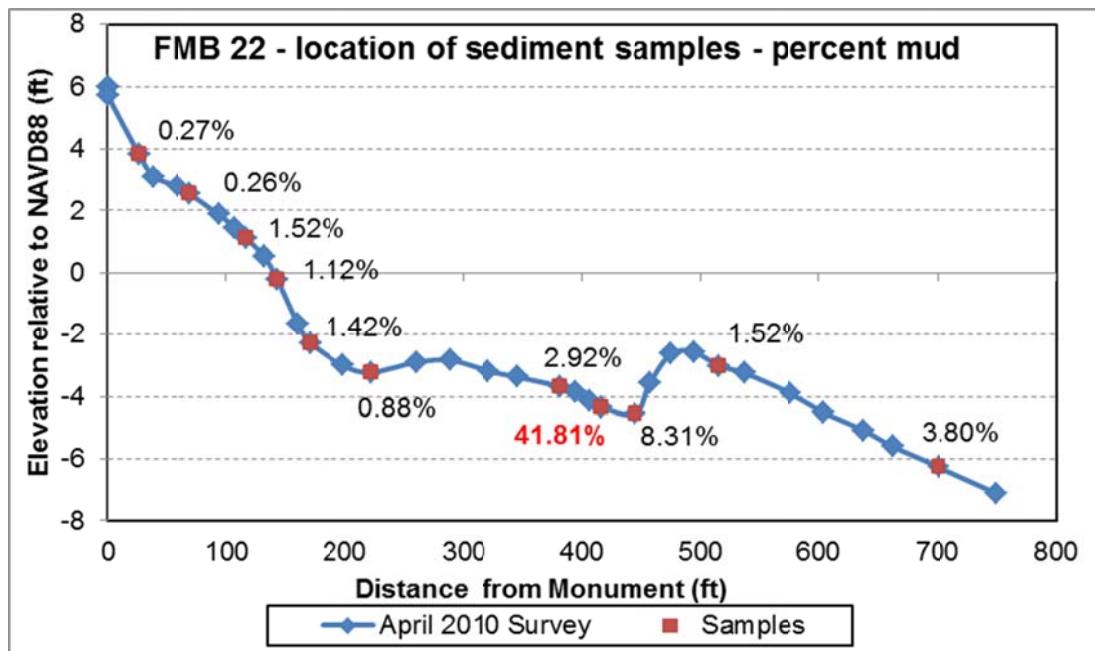


Figure 16. Beach Profile of FMB 22 with Sediment Sample Locations and Mud Percentages.

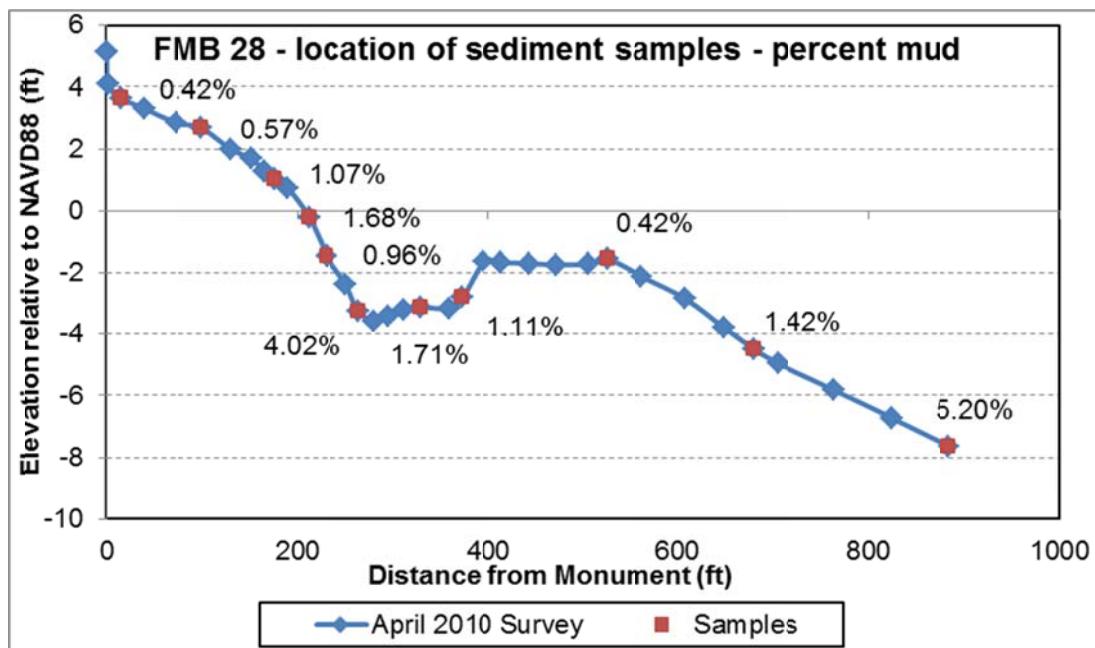


Figure 17. Beach Profile of FMB 28 with Sediment Sample Locations and Mud Percentages.

Control Area Northwest of Berm

Overall, the sediment in the control area northwest of the berm was much less muddy as compared to the berm area and the control area southeast of the berm. Mud content less than 2% was found in the surface sediment across the entire profile for transects northwest of the berm. Figures 18 and 19 show mud content of representative samples taken in the control area northwest of the artificial berm.

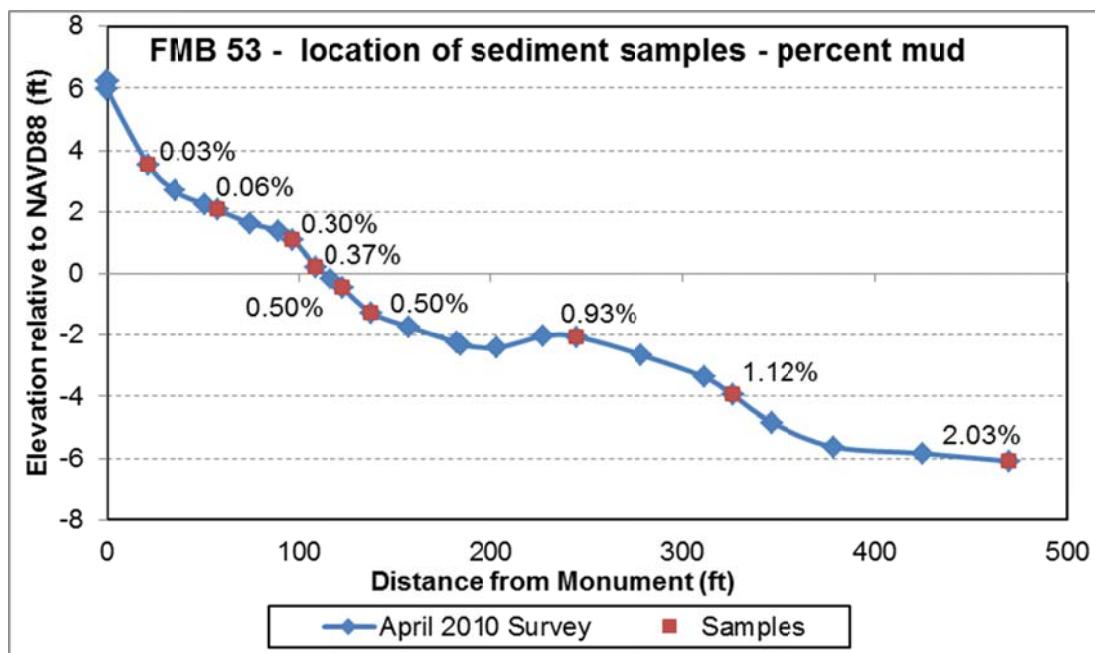


Figure 18. Beach Profile of FMB 53 with Sediment Sample Locations and Mud Percentages.

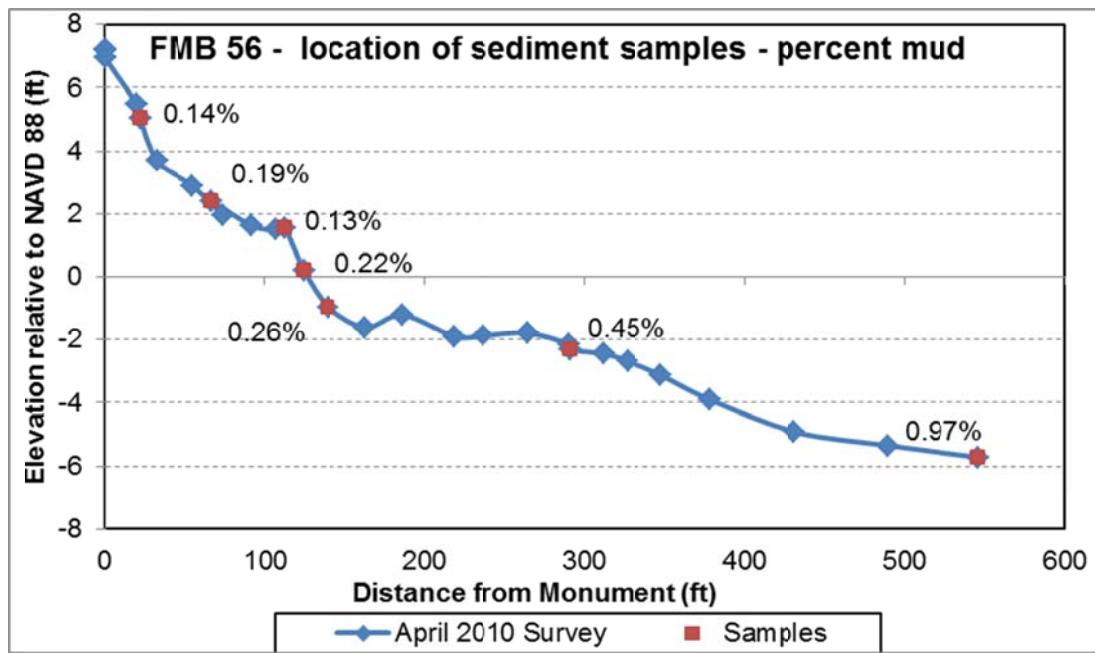


Figure 19. Beach Profile of FMB 56 with Sediment Sample Locations and Mud Percentages.

Carbonate Concentrations

Carbonate concentrations were generally highest in samples that contained more shell debris, which were in the swash zone, and also at the landward toe of the berm. The following section summarizes the longshore and cross shore distribution of carbonate grains.

Control Area Southeast of Berm

The highest carbonate concentration along the profiles in the control area southeast of the berm was located within the swash zone (approximately sample 4). High carbonate concentrations were also found offshore in FMB 3 (Figure

20). Figures 20 and 21 show the percentage of carbonate in each sample across the profile for two example profiles.

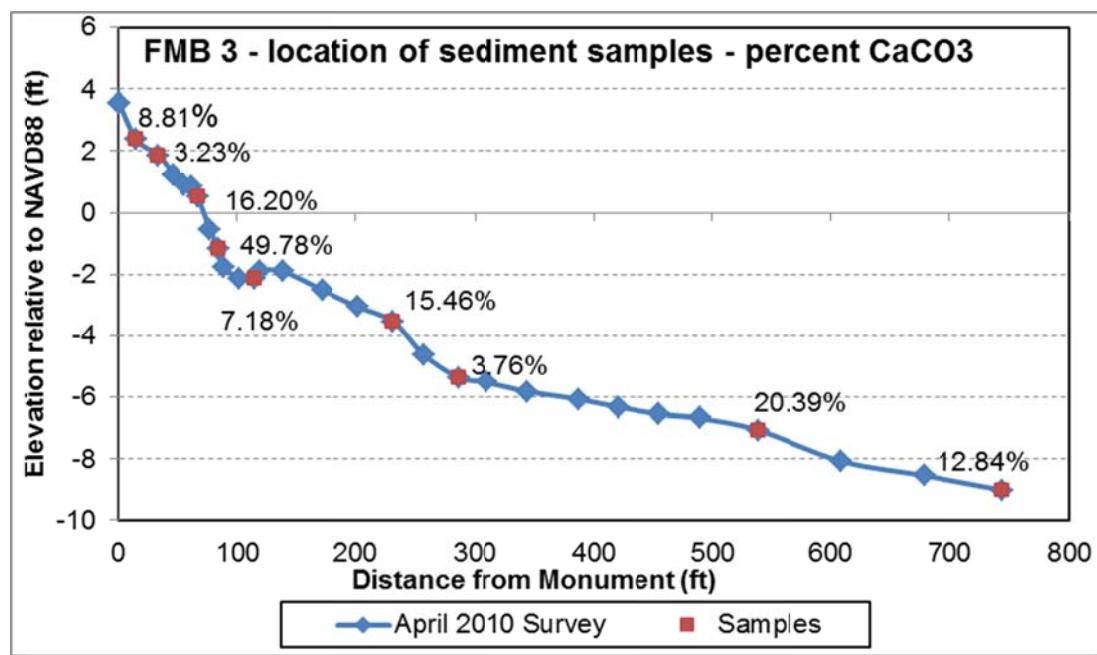


Figure 20. Percentage of Carbonate in Coarse Fraction of Samples along FMB 3.

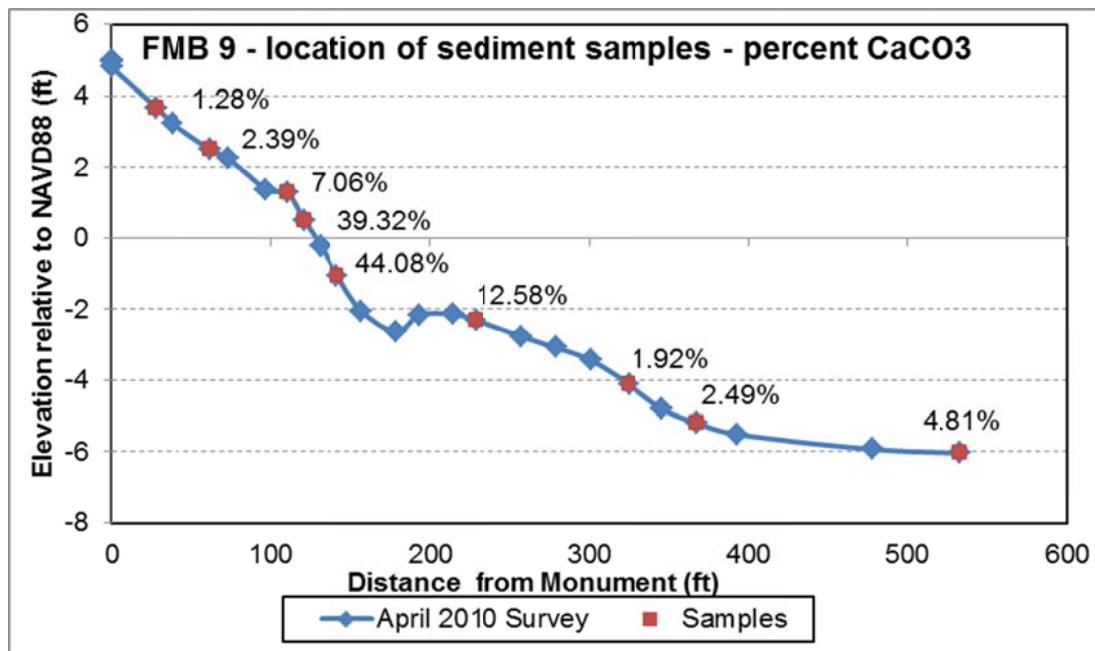


Figure 21. Percentage of Carbonate in Coarse Fraction of Samples along FMB 9.

Berm Project Area

Within the berm project area, the highest carbonate content in the sample profiles was also within the swash zone, as expected. Greater percentages of shell debris were also found at the landward toe of the berm. Across the artificial berm, the coarsest sediment with the highest shell debris content was found at the landward toe of the berm. This provides some evidence that coarser sediments tend to move landward, as often desired for berm nourishment, provided that wave energy is such that the coarse sediment can be mobilized. However, it is important to note that further investigation into the native beach prior to berm placement is needed to confirm this conclusion. Figures 22 and 23

show the percentage of carbonate in each sample across the profile for two example profiles.

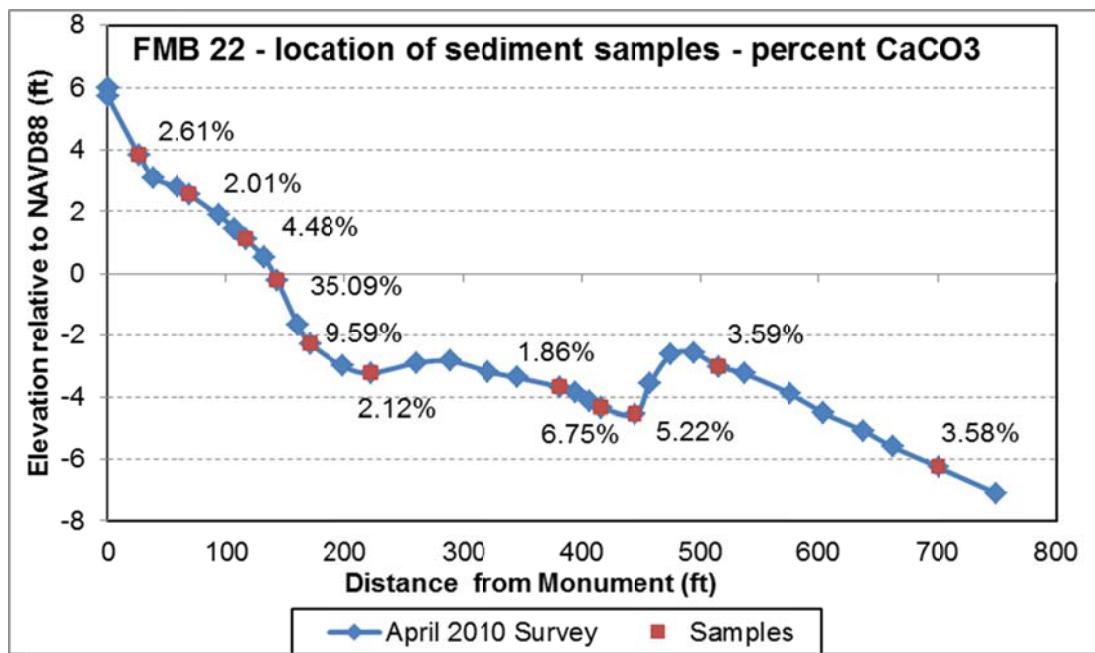


Figure 22. Percentage of Carbonate in Coarse Fraction of Samples along FMB 22.

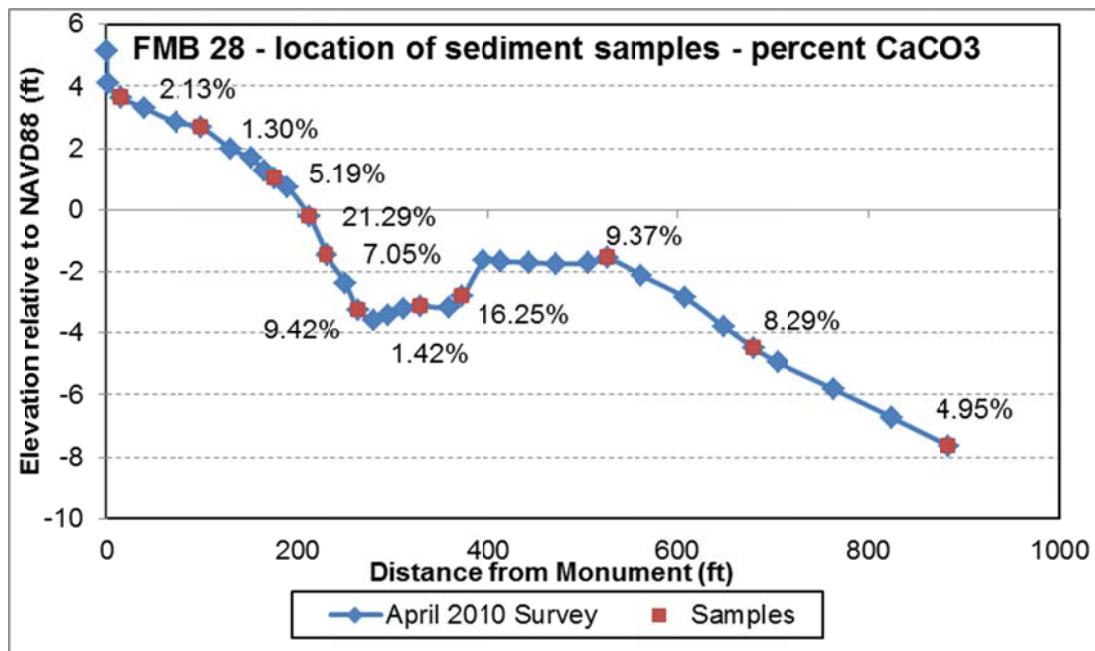


Figure 23. Percentage of Carbonate in Coarse Fraction of Samples along FMB 28.

Control Area Northwest of Berm

Within the control area northwest of the artificial berm, the lowest percentages of carbonate were measured (Figures 24 and 25). This is consistent with the relatively well sorted sand, as discussed above. Along the individual profiles, the highest carbonate concentration was located in the swash zone, as expected.

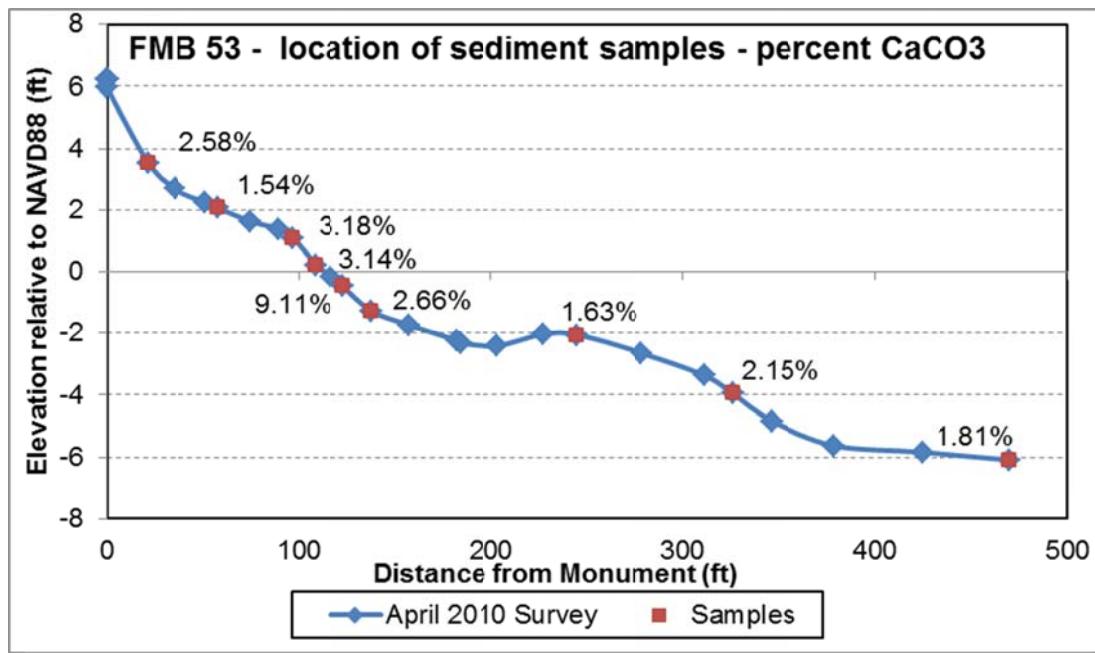


Figure 24. Percentage of Carbonate in Coarse Fraction of Samples along FMB 53.

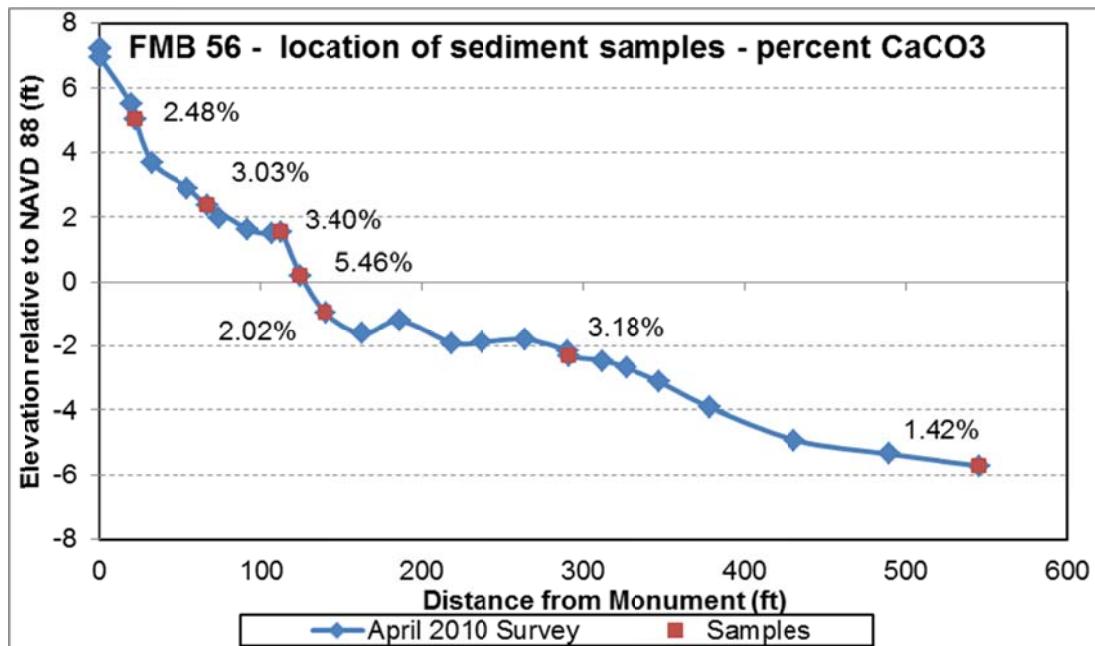


Figure 25. Percentage of Carbonate in Coarse Fraction of Samples along FMB 56.

Discussion of Sedimentological Characteristics

Generally, the study area contains moderately to well sorted very fine to fine sand. In the swash zone, high contents of shell debris were found, resulting in coarser sediment with poorer sorting. Offshore, the sediments tended to be moderately to poorly sorted, caused by a higher content of mud. In the artificial berm area, the dry beach, swash, and offshore samples were comparable to the control areas, however, sediments at the landward toe of the berm tended to be moderately sorted fine shelly sand, and on the top of the berm sediments were slightly finer moderately sorted fine sand.

Most of the sediment in the surface samples above mean sea level had less than 4% mud. Highest mud contents were found in the offshore of the control area southeast of the berm, and in the localized mud patches in the trough landward of the berm. In the control area northwest of the berm, minimal mud content of less than 4% was found. Figure 26 is a map showing the offshore mud sample percentages. All of the sample profiles with sample locations and mud percentages are included in Appendix D.

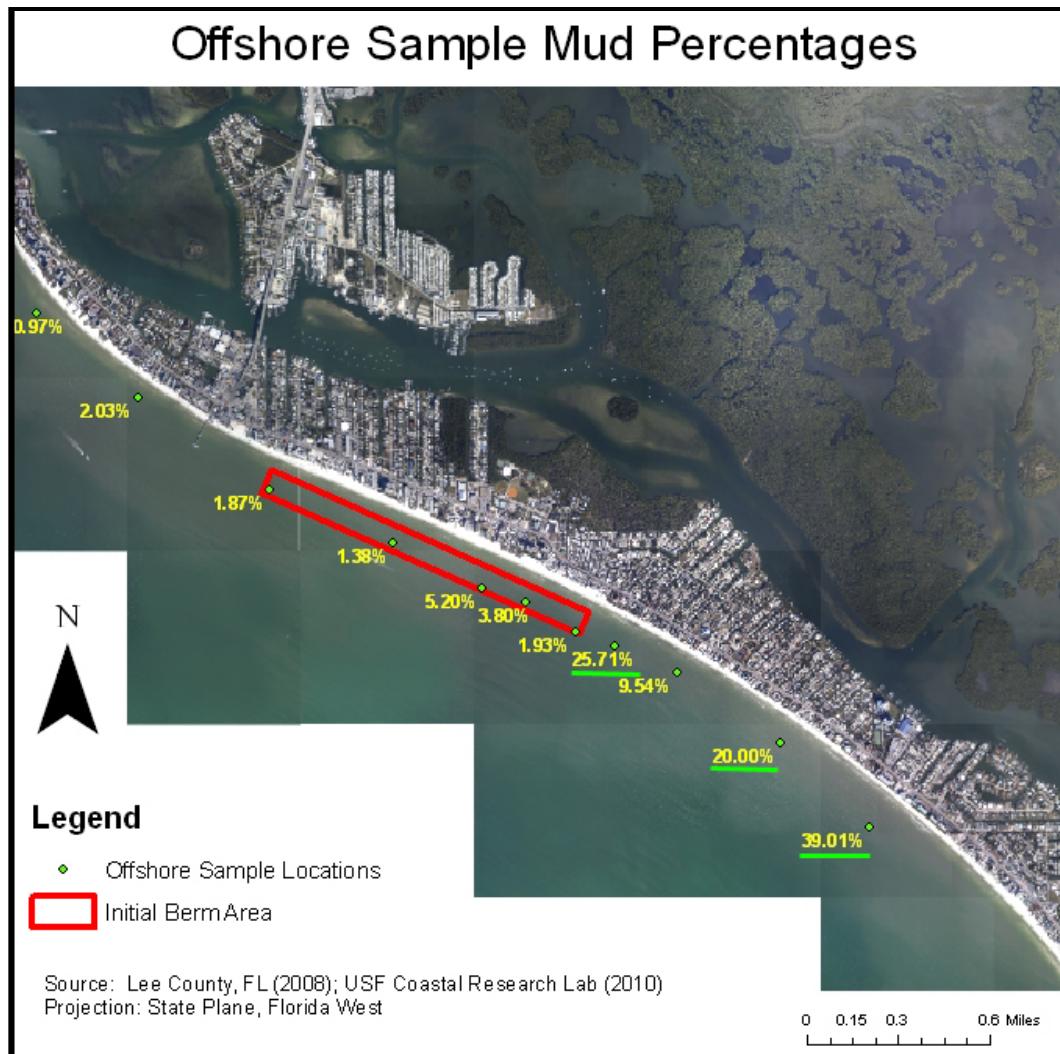


Figure 26. Percentage of Mud in the Surface Sediment Samples Collected at Approximately 8 ft Water Depth (NAVD88).

Except those from the offshore in the control area southeast of the artificial berm, most of the samples collected for this study showed mud percentages less than those found vibracores taken by USACE. During a study of a berm in Newport Beach, California, Mesa (1996) found that finer sediment was carried offshore, creating an overall coarsening of the dredged material. A similar trend

was found at the Fort Myers Beach berm. The previously mentioned surface sediment samples were taken approximately one year after the vibracores in Matanzas Pass were collected, therefore the mud percentages found may be lower because of winnowing of finer sediments, thus creating a now coarser berm. It is unclear at this point why the highest percentages of mud are located in the offshore region of the southeast control area. Future studies involving vibracores may answer the question as to whether the mud is native, or was brought to the area by the placement of the berm.

As expected, the highest percentages of carbonates were found in the swash zone. Northwest of the berm, carbonate content was lowest, however within the profile the highest percentage was also found in the swash zone. In the artificial berm area, elevated percentages of carbonates were found directly at the steep landward toe of the berm. The samples with the coarsest grain sizes were generally also those that contained the highest percentage of carbonates. Appendix E contains all sample profiles with sample locations and percentage of carbonates. The location of the coarse material in the landward toe of the berm and the fine material seaward of the berm seems to suggest that coarser sediment moved selectively onshore, while finer sediment moved selectively offshore over the berm with active sediment suspension and transport. However, the patches of mud found in the trough landward of the berm seem to conflict with the above understanding of landward transport of coarser sediment. The less energetic trough allows the deposition of finer sediment. This indicates that sediment transport and deposition may be more complicated than the simplified

understanding of landward transport of coarser sediment and seaward transport of finer sediment.

Morphological Evolution of the Artificial Berm

Morphological evolution of the artificial berm was quantified using the time series survey data. The following section discusses the pre-construction morphology, berm morphology after placement, and cross-shore and longshore morphological evolution of the artificial berm and control areas.

Pre-construction Morphology

Pre-construction morphology of Fort Myers Beach contained a small natural bar that has a height of about 1 ft, and approximately 300 ft offshore. The beach width was approximately 100 to 200 ft with a gentle slope. Figure 27 provides a representative profile of the study area surveyed in May 2009, before the construction of the nearshore berm. This morphology was representative of the entire study area.

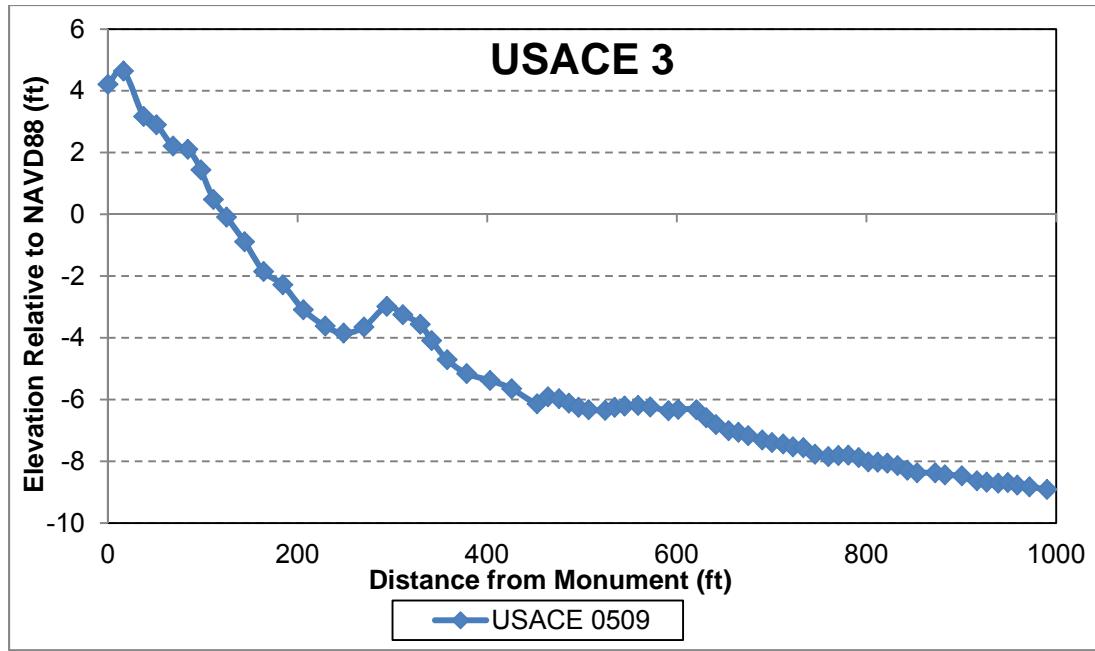


Figure 27. Beach Profile at USACE 3.

Profile averaging similar to that conducted by Larson and Kraus (1992a) was attempted (Figure 28). However due to highly variable offshore bathymetry, likely controlled by regional geology, large standard deviation about the mean occurred along the offshore portion of the profile. This contrasts the typical trend observed for profile averaging, with profiles converging in the offshore region (Wang and Davis, 1999; and Wang and Davis, 1998). Therefore, no representative spatially averaged profile can be obtained for the entire study area.

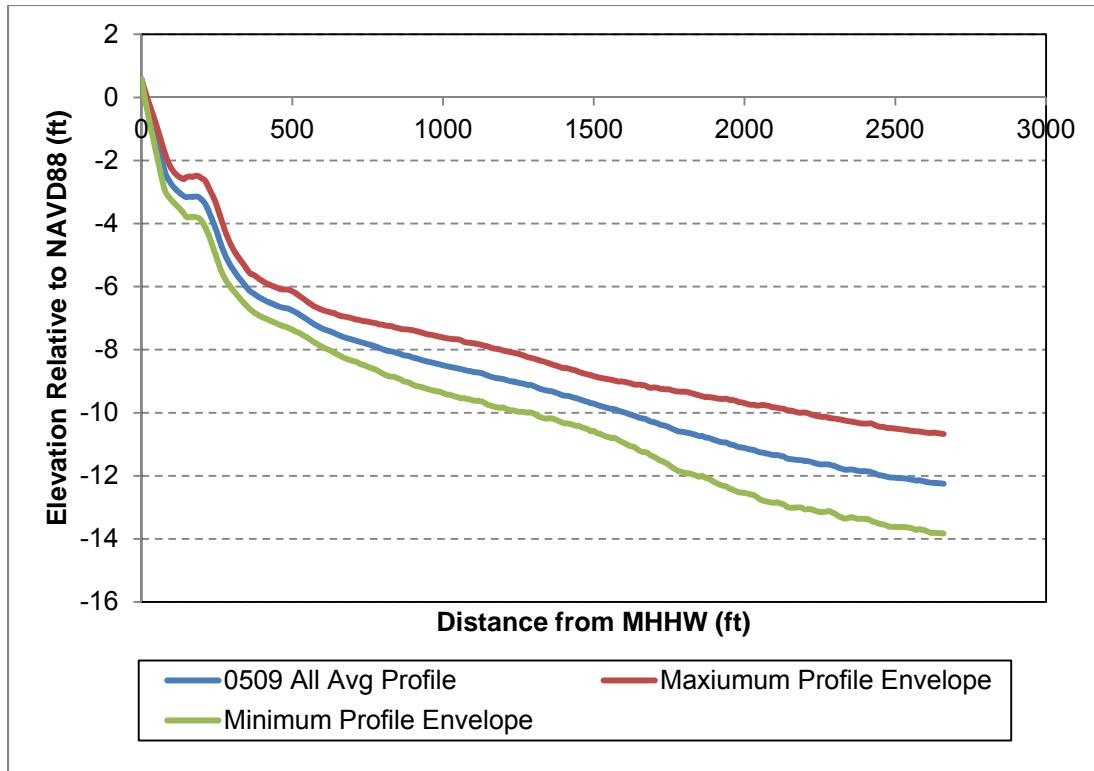


Figure 28. Spatially Averaged Profile from 0509 Surveys. Note the large offshore deviation from the average profile.

Post-construction Berm Morphology

While dredging Matanzas Pass in October 2009, dredged material was placed directly in a nearshore berm. A survey was performed immediately following the construction. The berm morphology was highly variable alongshore due to dredging and placing techniques. Figure 29 shows the longshore variability of the berm just after placement. All the distances are referred to the MHHW line (0.58 ft above NAVD88). Longshore variations occur in every part of the profile including foreshore slope, location and depth of the trough, the location, height, and width of the berm, and the depth and slope of the seaward

flank. Table 3 summarizes the characteristics of the berm profiles just after construction and emphasizes the longshore variability. Distance from the MHHW line to the berm crest varied between 124 ft to 321 ft. Height (defined here as the difference between crest and trough) and elevation (defined here as the elevation of the berm crest) of the berm varied by approximately 2.7 ft and 2.4 ft, respectively. Width of the berm ranged from 377 ft to 599 ft. This substantial longshore variation has considerable influence on the evolution of the artificial berm.

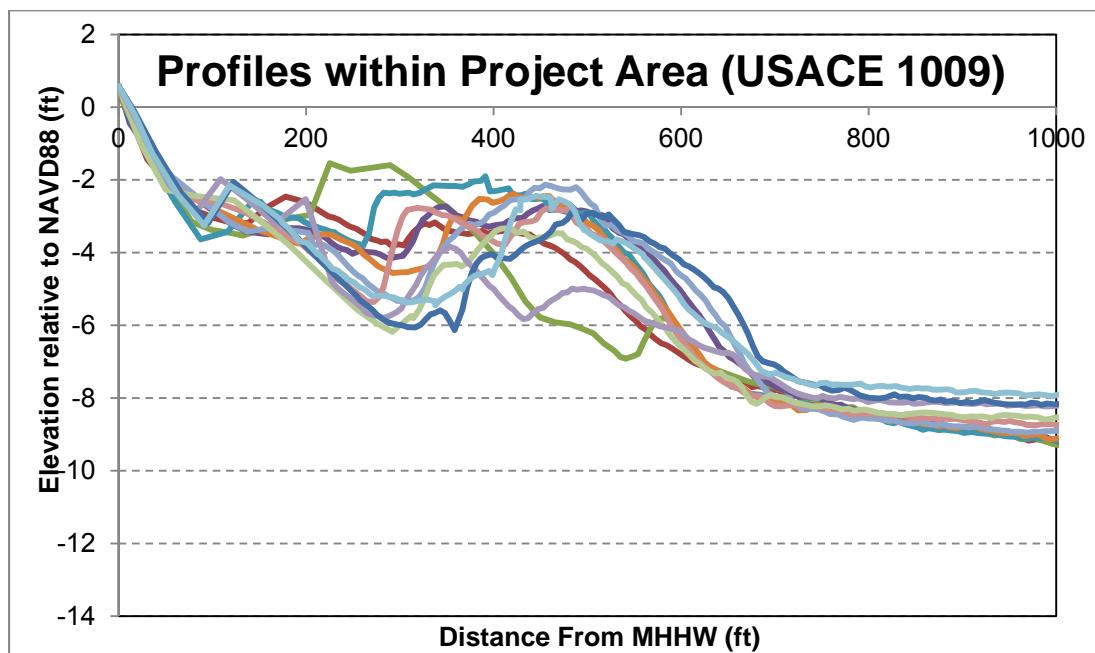


Figure 29. Longshore Variation of Profiles Within Project Area (1009). The profile was highly variable in every aspect, including foreshore slope, location and depth of the trough, distances to berm crest, berm heights, berm elevations, and berm widths, as well as the depth and slope of the seaward flank of the berm.

Table 3. Initial Berm Characteristics.

	Distance to Berm Crest (ft)	Berm Height (ft)	Berm Elevation (ft)	Berm Width (ft)
USACE 9	328	0.6	-3.2	407
USACE 10	224	1.9	-1.5	436
USACE 12	344	1.4	-2.7	391
USACE 14	283	1.4	-2.4	426
USACE 15	387	2.0	-2.5	338
USACE 16	452	3.1	-2.2	332
USACE 17	315	2.5	-2.8	384
USACE 18	406	2.9	-3.3	274
USACE 19	354	1.9	-3.9	384
USACE 20	481	3.1	-2.9	326
USACE 21	442	3.0	-2.4	293
Average	365±74	2.2±0.8	-2.7±0.6	362±51

This table displays the initial berm characteristics including distance to the berm crest from MHHW, the berm height (measured from the elevation landward trough to the elevation berm crest), berm elevation (relative to NAVD88), and berm width.

Initial volume was reported in the construction notes by the Jacksonville District (USACE) to be 229,313 cu. yd. Based on the pre and post construction profiles, a berm volume of 210,526 cu. yd. was obtained. This is within 10% of the volume reported during construction, and may be accounted for loss of sediment through the dredging and placement process. It may also be that alongshore coverage of the pre- and post- construction survey data had insufficient resolution to capture the lateral ends of the berm, which could account for this difference. The length of the project was calculated from the survey data to be approximately 5370 ft.

First Year Morphological Evolution of the Artificial Berm

At the southeastern edge of the project area, berm heights were relatively low, with a landward moving trend. Figure 30 compares the survey performed by USACE in October 2009 to the surveys performed by USF CRL in April and October 2010 along profile FMB 18, which is located at the southeastern edge of the berm. The berm height at FMB 18 was relatively low at less than 2 ft and remains constant during the first year. The overall profile volume stayed rather constant, with a small net gain of 3.31 cu. yd/ft, indicating that cross shore sediment transport dominates during the first year. During the first 6 months, the two bar morphology remained, while the entire system migrated onshore for about 100 ft. The beach and nearshore area landward of the artificial berm remained stable over the initial 6 month period. During the second 6 months, the small bar closer to the shoreline migrated and attached itself to the shoreline, resulting in beach accretion.

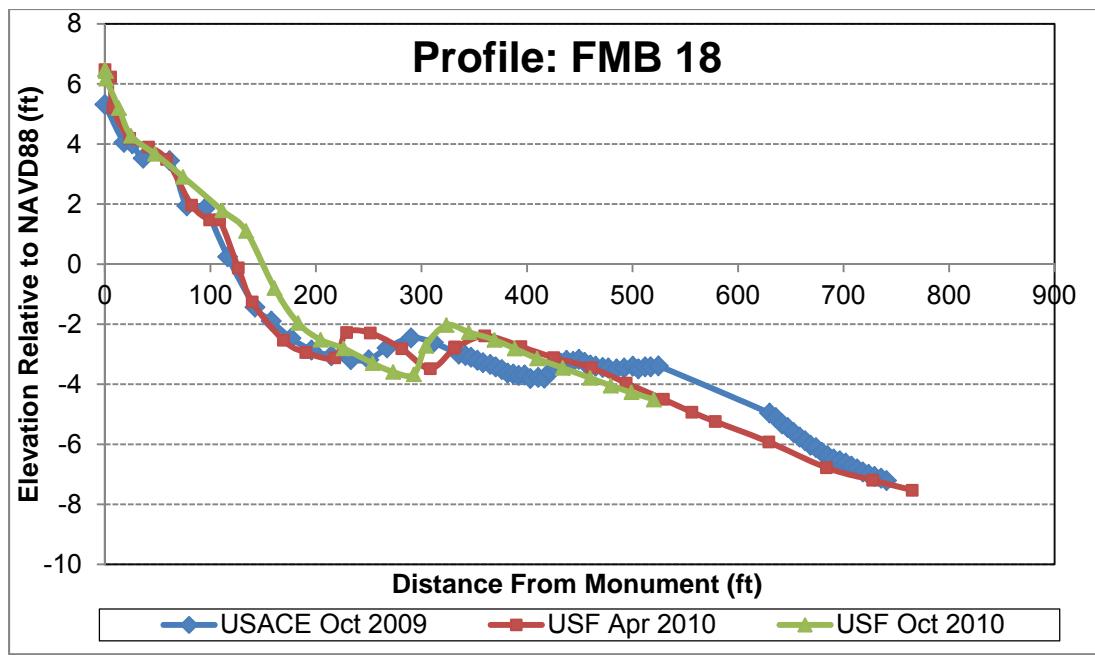


Figure 30. Time Series Beach Profile at FMB 18.

In the middle of the berm project area, the bar migrated onshore considerably, while berm heights remained fairly constant. Figure 31 shows an example of a profile in the middle of the berm, and exhibits representative morphologic evolution of the project area. The berm height measured from trough to crest was about 3 ft, and remained fairly stable throughout the first year. Within the central portion of the project area, most of the profile over the berm illustrated an onshore migration of nearly 200 ft during the first 6 months (Figure 31). In addition to onshore migration, the berm crest elevation increased by approximately 1.5 ft at this location. The shape of the berm changed from a roughly symmetrical bell curve to a sharply skewed bar with a steep landward slope. The total volume of the berm was roughly maintained as it migrated landward and upward (small loss of 2.67 cu. yd/ft across the entire profile), with

erosion on the seaward slope and deposition in the prior trough location. The landward migration continued during the second 6 months, but at a much reduced rate, while maintaining the skewed shape of the berm. The beach and nearshore area landward of the artificial berm remained stable over the first year after the construction.

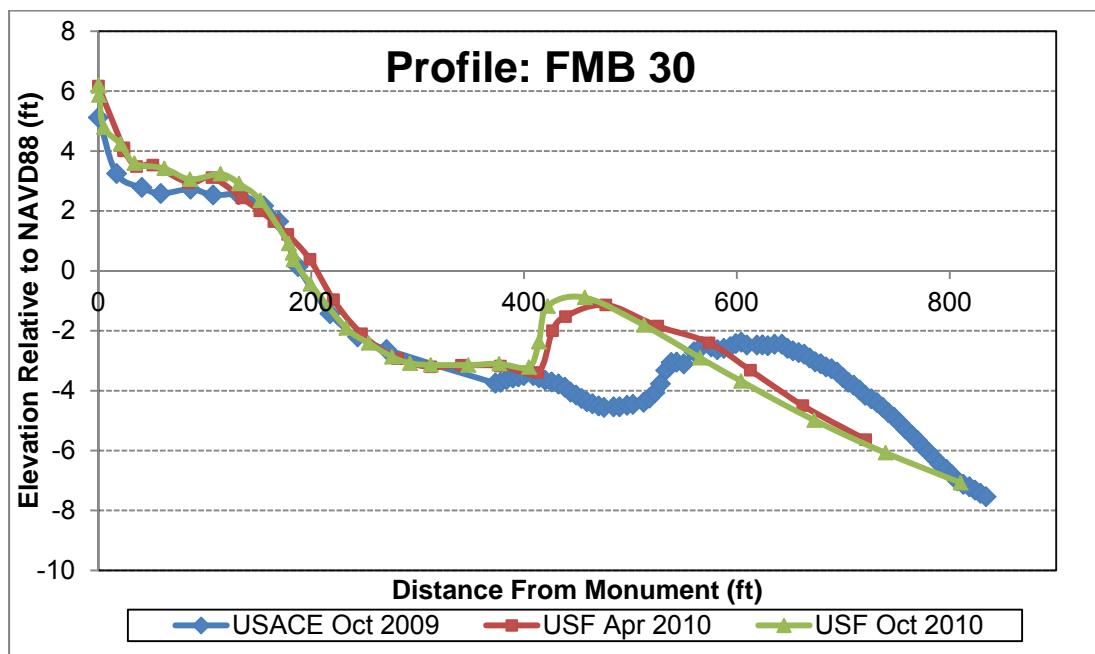


Figure 31. Time Series Beach Profile at FMB 30

The control area southeast of the berm (Figure 32) had a small natural bar of less than 2 ft in height. The height and volume of this bar was much smaller than the artificial berm. Similar to the artificial berm, the natural bar migrated onshore during the first 6 months, however, for a distance of approximately 60 ft, which is much shorter than the onshore migration rate of the artificial berm. Different from the artificial berm case, the onshore migration of the bar resulted

from modest erosion at both the seaward slope and in the nearshore zone, instead of just at the seaward slope for the artificial berm. During the second 6 months, the bar remained stable. The dry beach also remained stable throughout the entire first year.

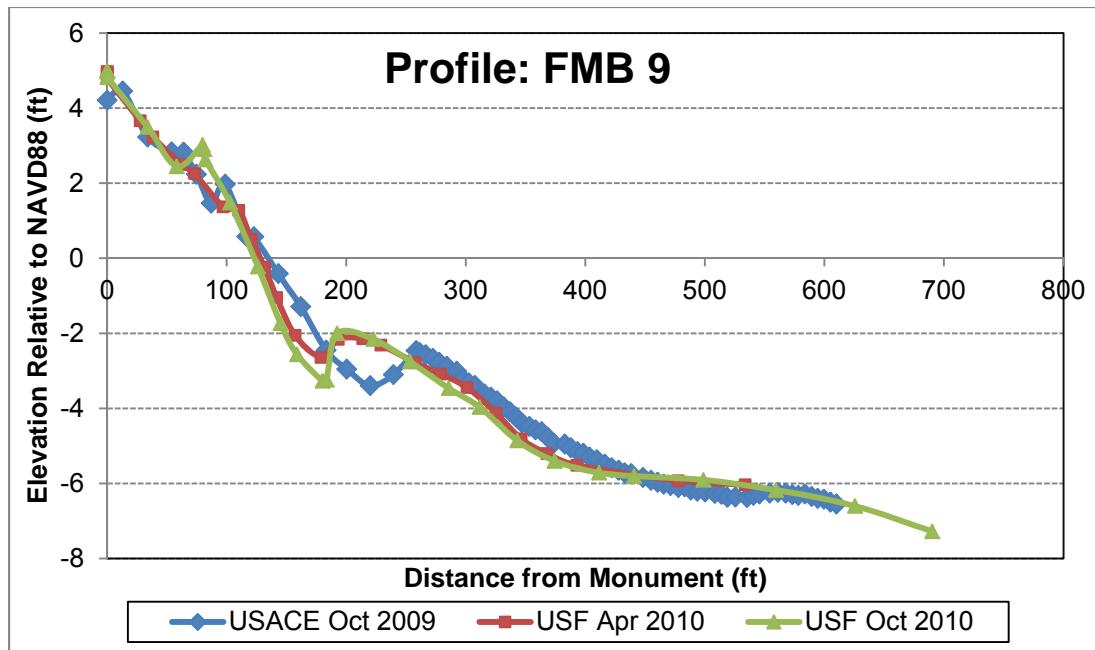


Figure 32. Time Series Beach Profile at FMB 9.

Compared to the profiles discussed above, FMB 54, located to the northwest of the artificial berm, demonstrated a different trend of evolution (Figure 33). Except for a small amount of accumulation in the trough area, erosion occurred across nearly the entire profile during the first 6 months. This profile is rather close to the recently dredged Matanzas Pass, and may be influenced by inlet processes. During the second 6 months, the small bar (less than 1 ft high) that developed in the previous trough moved offshore to roughly

the location of the prior bar, while the dry beach remained stable. Overall, the magnitude of the profile changes during the year was small.

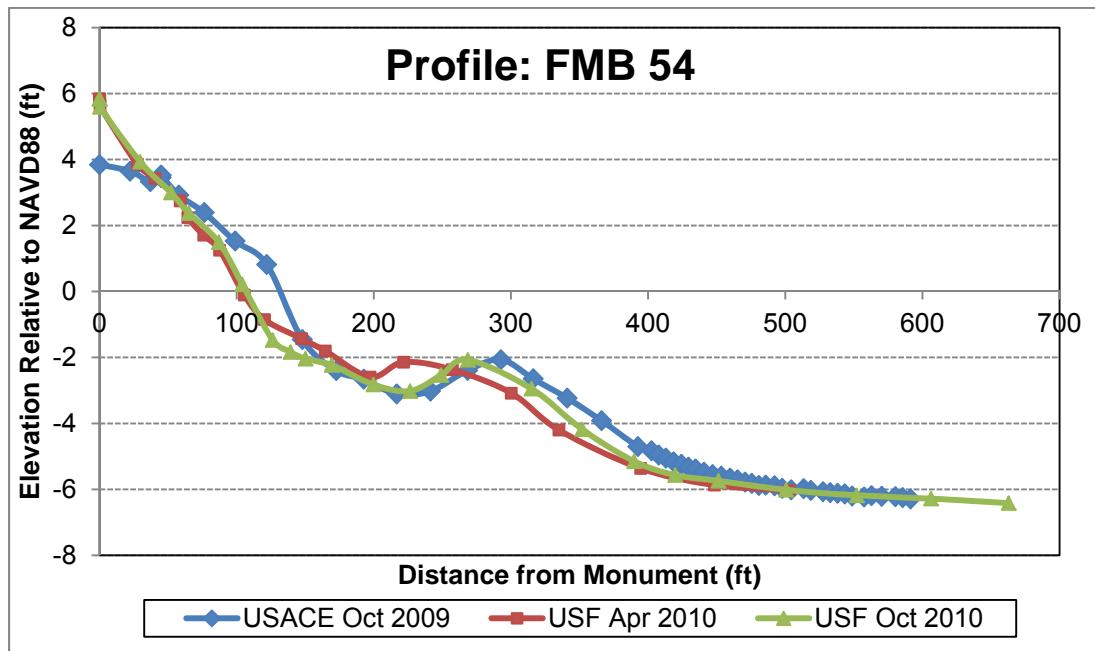


Figure 33. Time Series Beach Profile at FMB 54.

Longshore morphology of the bar remained highly variable, as can be seen in Figure 34. All of the lines are referenced to MHHW. Similar to the immediate post-construction profiles shown in Figure 29, all portions of the profile exhibited longshore variations. Generally, however, the berm has migrated onshore, and the profiles are more variable in the nearshore. Compared to the initial placement, the overall shape of the berm seems to be narrower, with a steeper landward slope, and a gentler seaward slope.

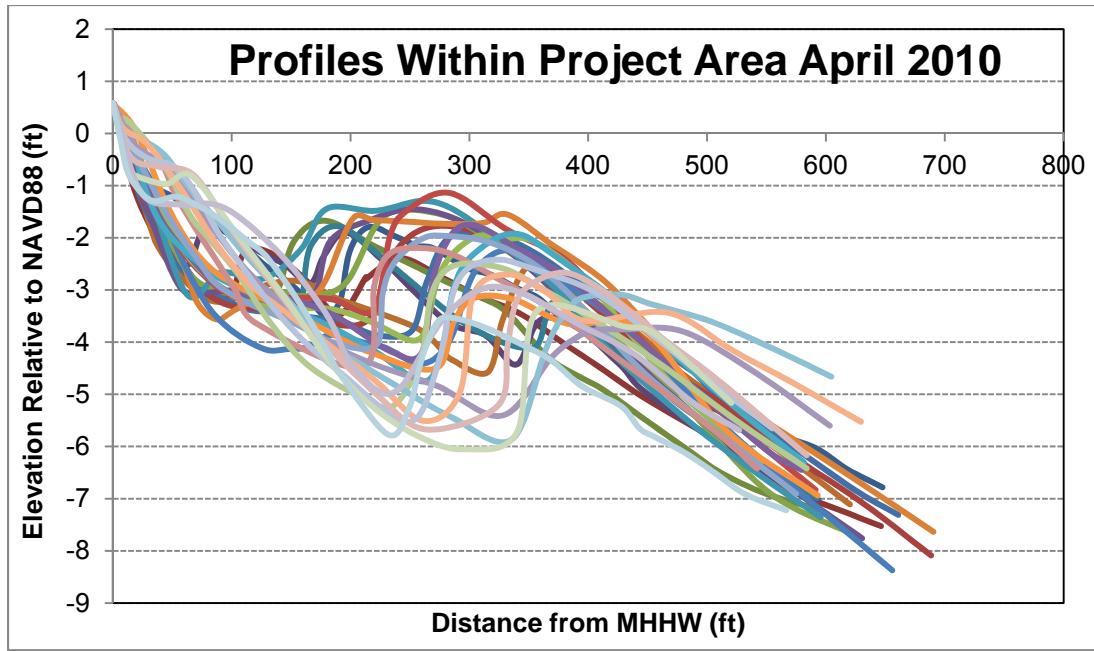


Figure 34. Longshore Variations of Profiles Within the Project Area (0410). All 30 USF profiles across the artificial berm, referred to the MHHW line. Note the substantial longshore variation of the morphology.

Along with the variability in the longshore, several trends were also identified. A relationship between the distance of the berm crest to the location of MHHW was evident. Lower berm crests correspond to a longer distance to MHHW, while an increasing berm elevation corresponds with decreasing distance to MHHW (Figure 35). This relationship is qualitative, however. For example, a similar berm height does not necessarily correspond to similar distance to MHHW at a different longshore location. Figure 35 also illustrates the location of the previously mentioned gaps that were created during construction. The gaps are not exactly equally spaced, but do not appear to be random either, and vary in elevation.

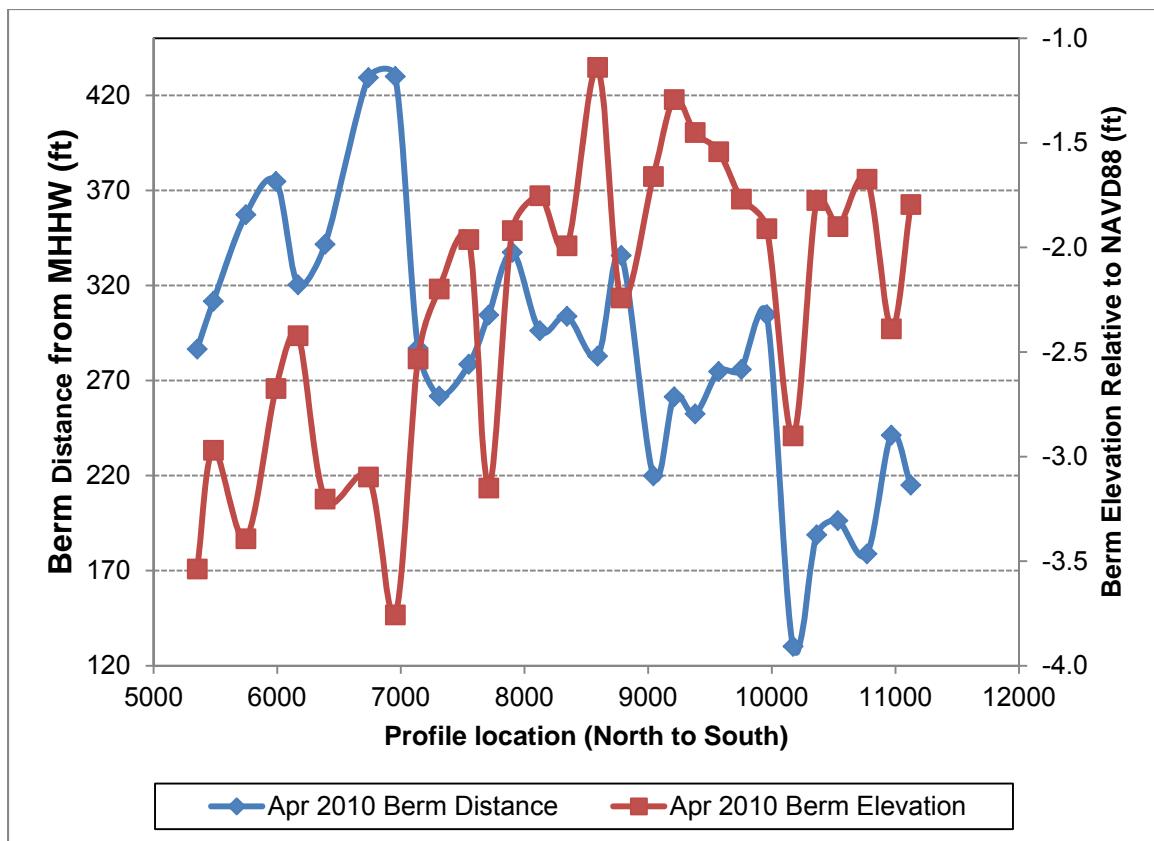


Figure 35. Longshore Variation of the Distance of the Berm Crest to MHHW and Berm Crest Elevation. Profile location is referred to the distance from the northwestern most profile.

Considerable longshore variations of the berm crest elevation occurred between October 2009 and October 2010 (Figure 36). Overall, the berm crest elevations increased reflecting the general trend of onshore and upward migration during the first year. Figure 37 depicts berm migration and berm crest elevations. Again, an overall increase in berm elevation can be seen throughout the first year, with a trend of higher elevations to the south. Several of the profiles were not surveyed in October 2009 and October 2010. Figures 36 and

37 also reveal that the surface of the berm was not uniform in terms of elevation, rather it undulates approximately 0.5 ft to 1 ft. The previously mentioned gaps are also illustrated, however, these simplified 1-D plots do not provide an accurate representation of the 3-D gaps as many of them are at an oblique angle to the shoreline (Figure 38), and need to be further illustrated and explained using beach profiles and contour maps.

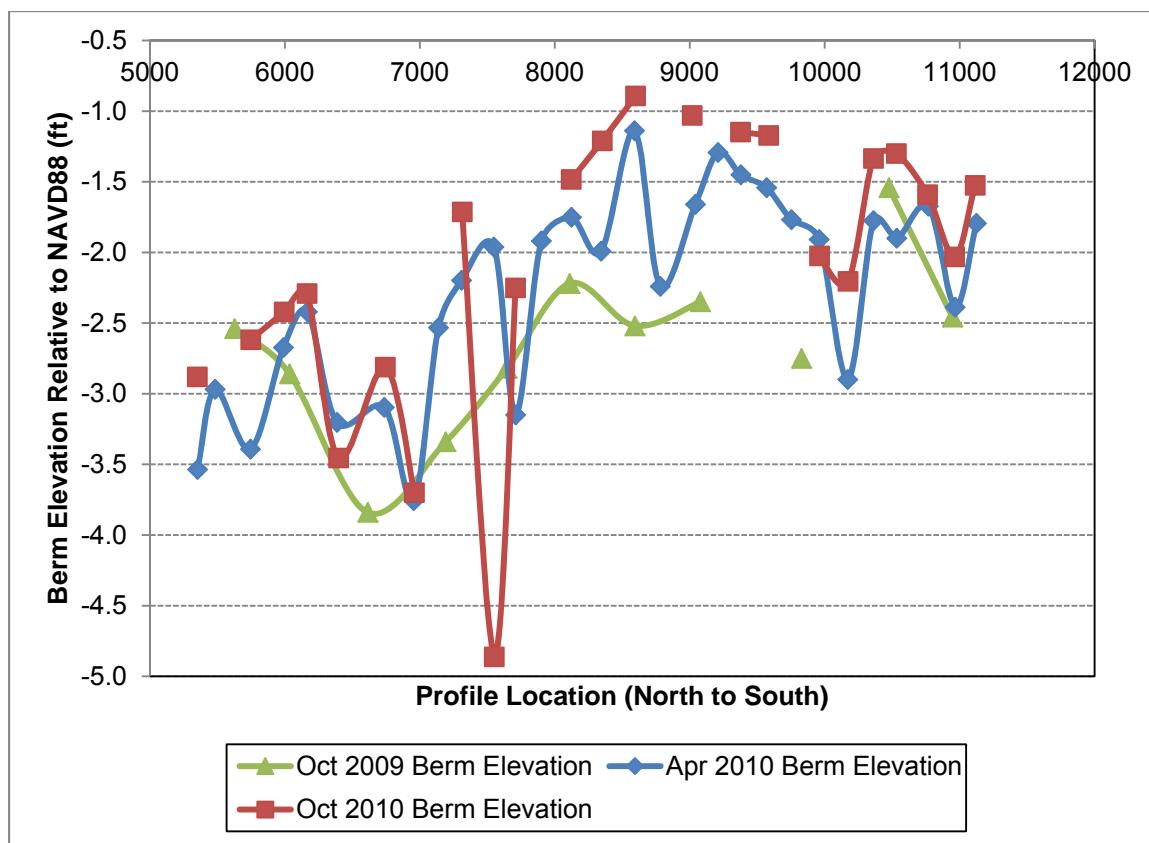


Figure 36. First Year Berm Elevations. Note the overall trend of an increase in berm elevation for the 6 month period.

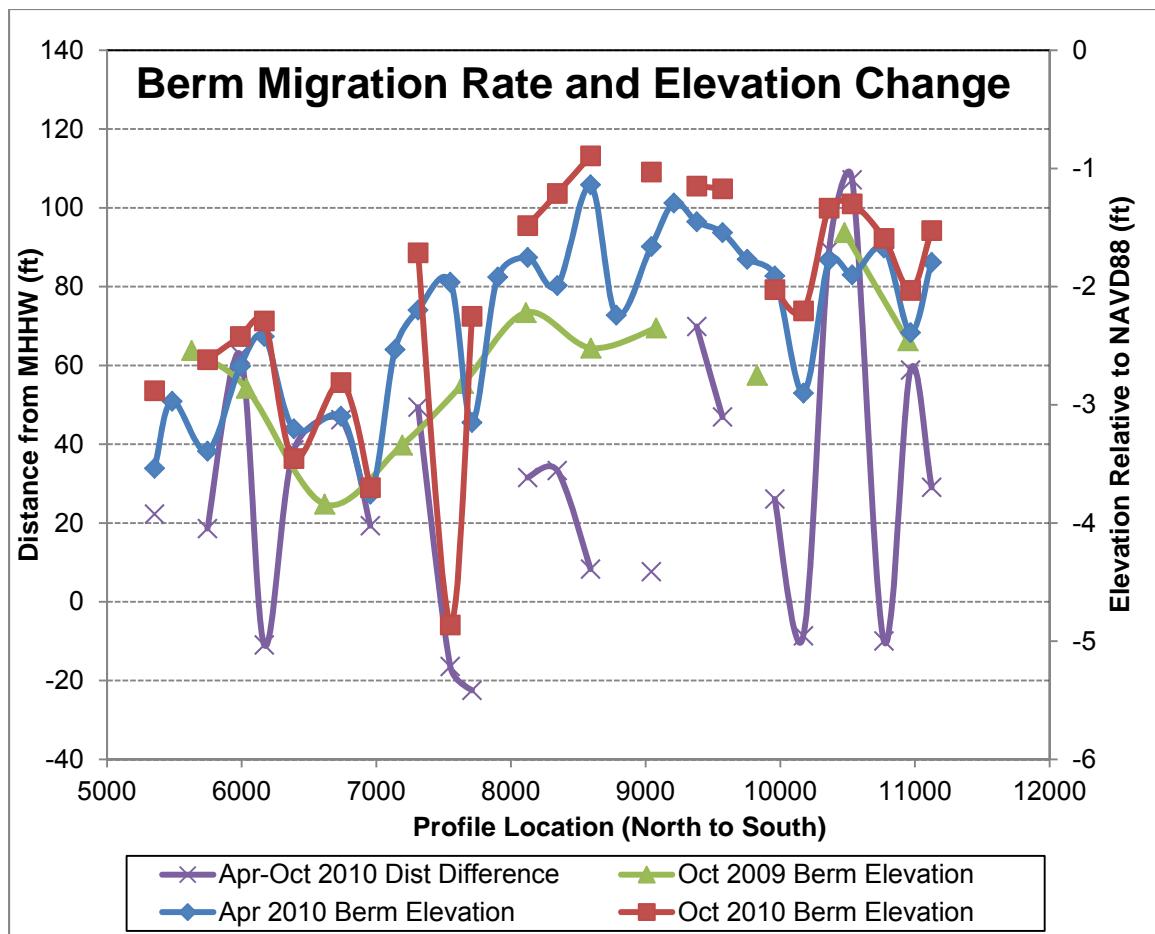


Figure 37. Longshore Variations of Berm Crest Elevation and Berm Migration Rate. Profile location is referred to distance from the northwestern most profile. Note the overall berm elevation increase for the first year. During the second 6 months, the artificial berm moved onshore, mostly less than 50 ft, with considerable longshore variations.



Figure 38. Longshore Variations in the Berm (March 2010). Notice that the gaps in the berm are at an oblique angle to the shoreline.

According to construction notes from the USACE Jacksonville District, because of dredging and fill techniques, gaps of less than 50 ft wide were created (Figure 39). The gaps are seen in the USF profiles as well (Figure 40 and 41). Because of the oblique angle to the shoreline (Figure 38, the southern two arrows), some of the gaps appear to split the berm alongshore creating a morphology that resembles a two bar system, with overall lower berm heights (Figure 40). Other gaps appear to be less oblique (Figure 38, northern most arrow), and simply exhibit a lower berm height (Figure 41). The gaps are likely maintained and modified by rip currents during high energy conditions. Future studies will confirm this. One example of a substantial gap that seems to have

formed is located at profile FMB 35 (Figure 42). In April 2010, the berm morphology in this profile was consistent with the other profiles in the berm project area, but by October 2010, the berm was no longer there. Because the change is so extreme for this low energy coast, and contrasted to the much more subtle morphology changes measured elsewhere, it is suspected that this occurred through anthropogenic influences (as confirmed unofficially by a beach attendant, possibly to increase access to and from the beach for recreational watercraft). Appendices F and G contain all USACE and USF beach profiles, respectively.

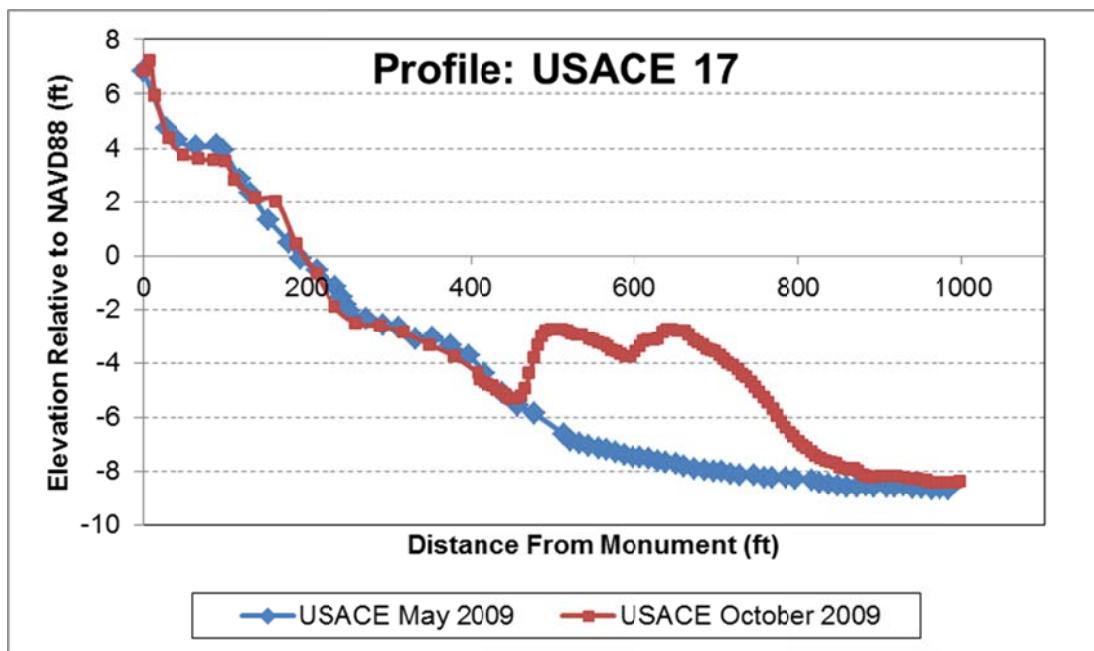


Figure 39. Profile at USACE 17. Note the small gap created during construction.

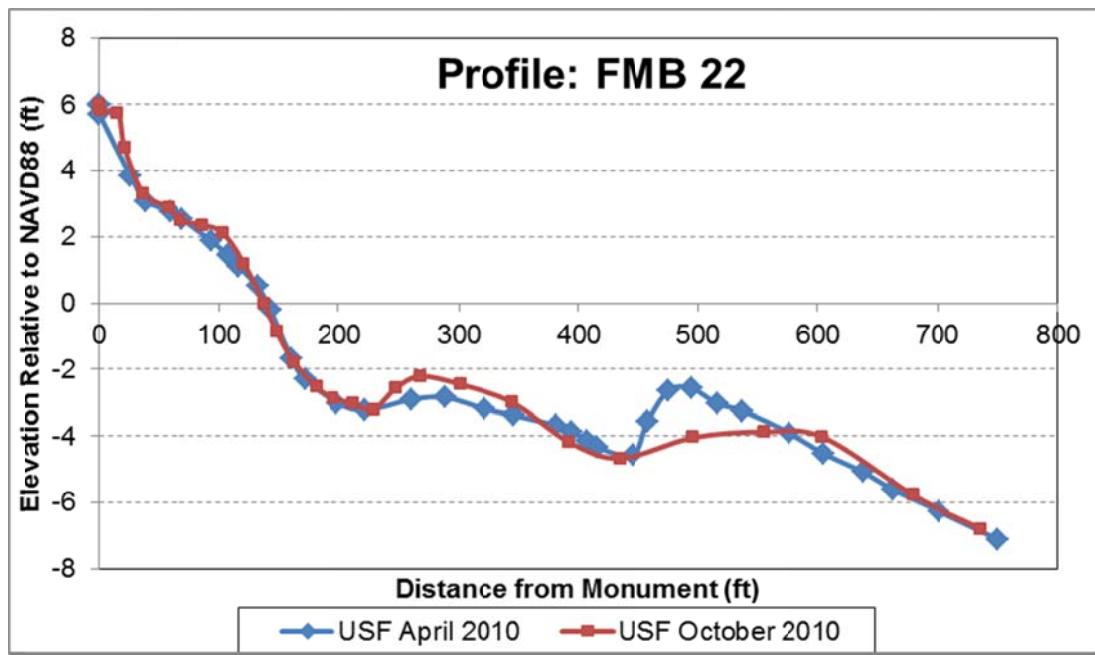


Figure 40. Profile at FMB 22.

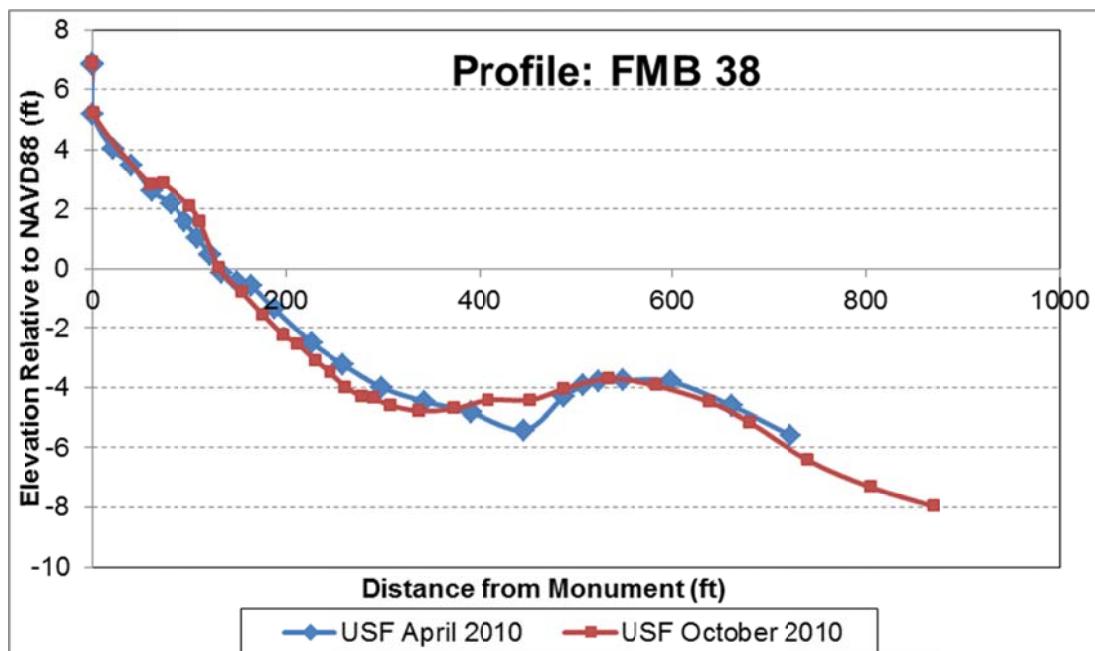


Figure 41. Profile at FMB 38.

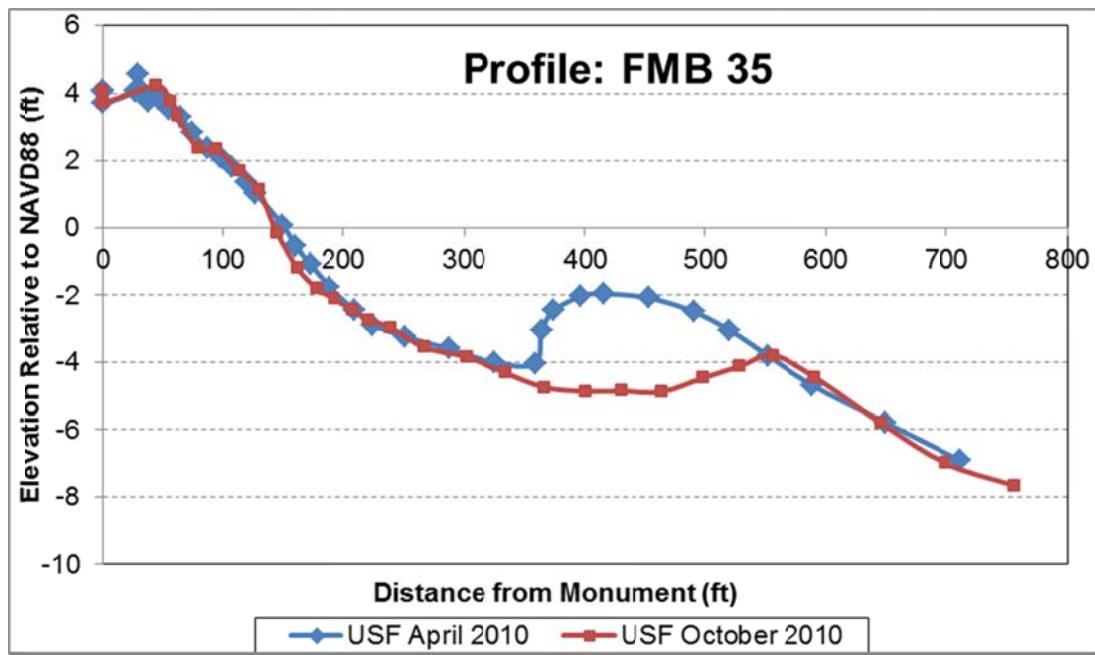


Figure 42. Profile at FMB 35. The blue line represents the profile in April 2010 when the berm was present. Six months later (red line) the berm is no longer seen at this location, i.e. a gap was formed, or was intentionally created.

Based on volume calculations using USF CRL's April and October 2010 survey data, no clear trend of volume change across the profiles can be identified. Figure 43 depicts the total volume change, as well as the beach/nearshore and bar volume changes. Beach/nearshore is defined as the zone from the monument to the trough, and berm is defined between the trough to the depth of closure. Included in Figure 43 are the 30 lines across the berm, as well as 3 lines north and 3 lines south of the berm. Although there was no definite trend of volume changes within the berm area, the 3 lines south of the berm gained sand, while the 3 lines north of the berm lost sand. It is possible that net longshore transport to the north is partially impounded downdrift by the

nearshore berm, reduced within the sheltered region of the berm, thereby reducing sand transport to the beaches north of the berm. Placement of the berm may be functioning as a submerged breakwater to decrease the longshore transport along the shoreline similar to what was documented in a study by van Duin, et al. (2004). Through these calculations it was also discovered that the length of the project area has increased to approximately 5840 ft, indicating that the bar has diffused in the longshore, which has been seen in several prior studies (Otay, 1995; Work and Otay, 1996).

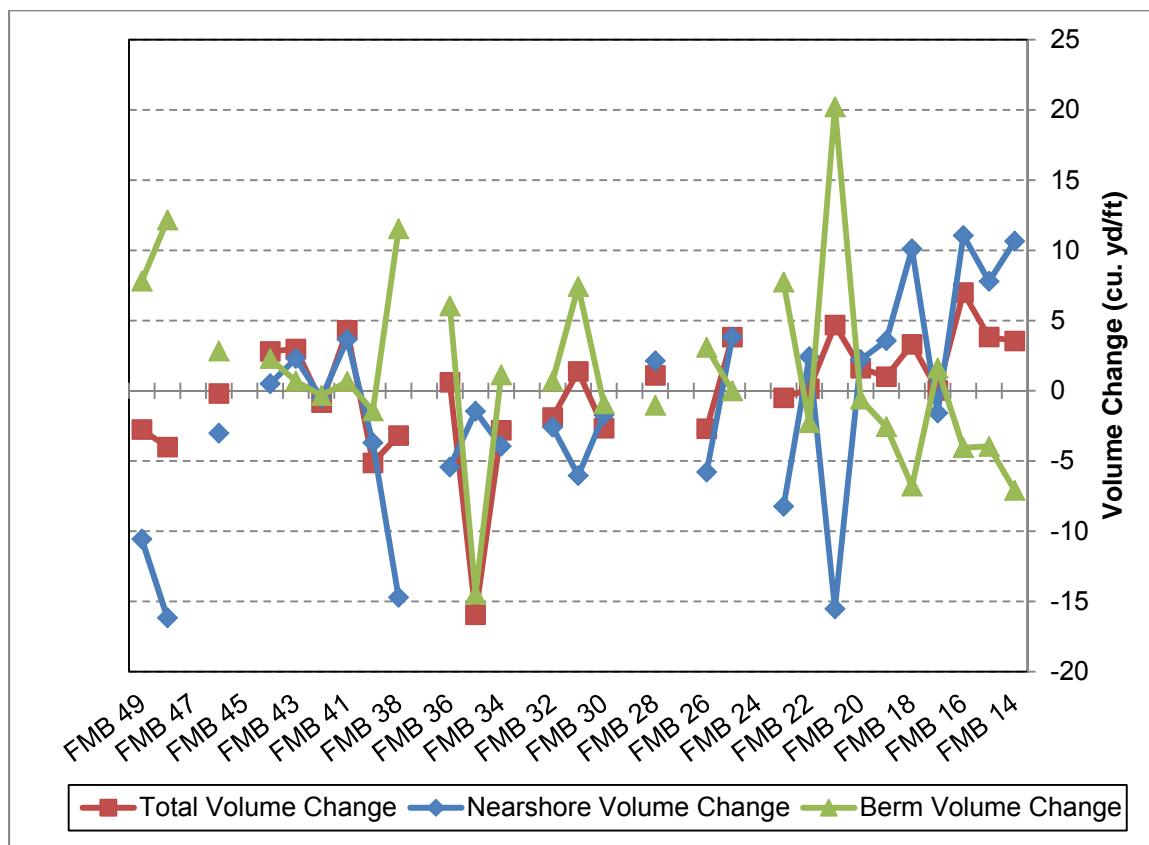


Figure 43. Volume Change Across Berm Profiles.

Since the construction of the berm in October 2009, it is apparent based on field observations that a salient has formed behind the northwestern portion of the berm. Figure 44 is a map that was created using shoreline survey data at the MLLW line in April 2010, as compared to a reference line that follows the trend of the overall shoreline, and illustrates a salient that formed at the northwestern end of the berm area immediately after placement, although it is not known what the shoreline morphology was immediately prior to berm placement. The formation of a salient may indicate that the berm was acting as a submerged breakwater (Zwamborn, Fromme, and Fitzpatrick, 1970).

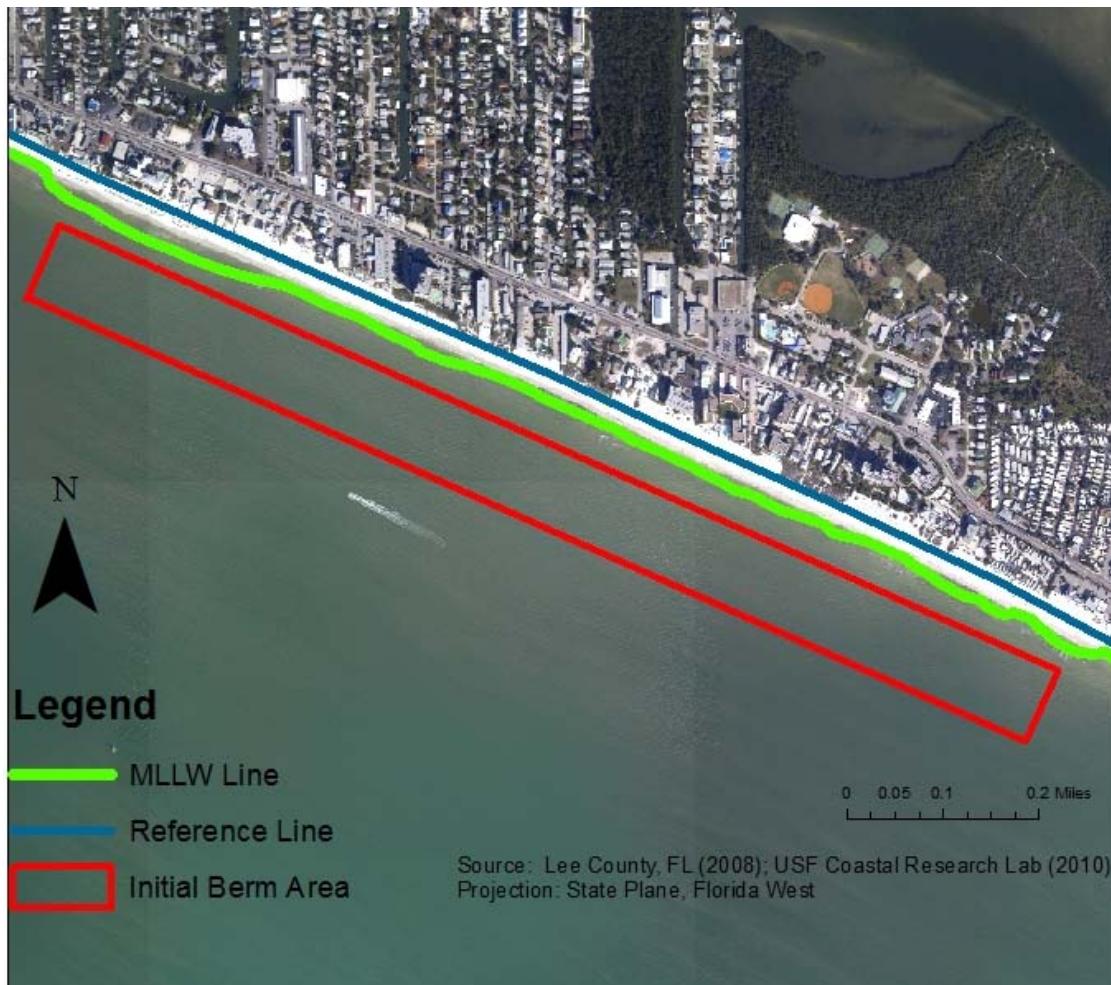


Figure 44. Map of the Berm Area and Shoreline in April 2010. The aerial photograph was taken in 2008, before the berm was placed. The green line follows the MLLW line. Note the salient that has formed in the northwest portion of the berm project area.

Discussion of Morphological Evolution

Generally, the berm shows a trend of onshore migration, with an increase in elevation the first year after construction. Berm height, defined as the elevation difference from the berm crest and the trough, remains largely stable.

Based on survey data collected by USACE and USF CRL, the berm has spread laterally by approximately 450 ft, and has changed from a symmetrical bell shape to an asymmetrical shape skewed landward, which illustrates the morphologic characteristics of an onshore migrating bar. Gaps that are approximately 50 ft wide were created as a result of construction, and seem to be dynamic and maintained by rip cells during high energy events.

The berm morphology is highly variable in the longshore, as is profile volume change. The patterns of profile volume change at the terminus of the berm seem to indicate that longshore sediment transport is to the north. A salient has also formed landward of the northern portion of the berm indicating that the berm is functioning to a certain extent as a submerged breakwater. Figures 45, 46, 47, and 48 display contour maps of the study area through the first year after construction. The black rectangle in each of the figures represents the designed berm placement area. Figure 45 is a contour map of the area pre-construction in May 2009 created using USACE survey data. Figure 46 is a map of the same area immediately after the berm was constructed in October 2009. The longshore variations of the constructed berm are apparent, especially in the northwest where there is a large gap in the berm, as well as the various elevations of the berm. Figure 47 displays the berm after the first 6 months. The berm has migrated onshore, and in some places has almost attached to the shoreline. Several gaps can be seen across the berm, as well as the slight changes in the shape of the shoreline. The berm has spread slightly in the longshore, especially to the northwest. Figure 48, created from surveys taken by

USF in October 2010, shows the less rapid onshore migration during the second 6 months. The gaps are still maintained during this time period, although at slightly different locations.

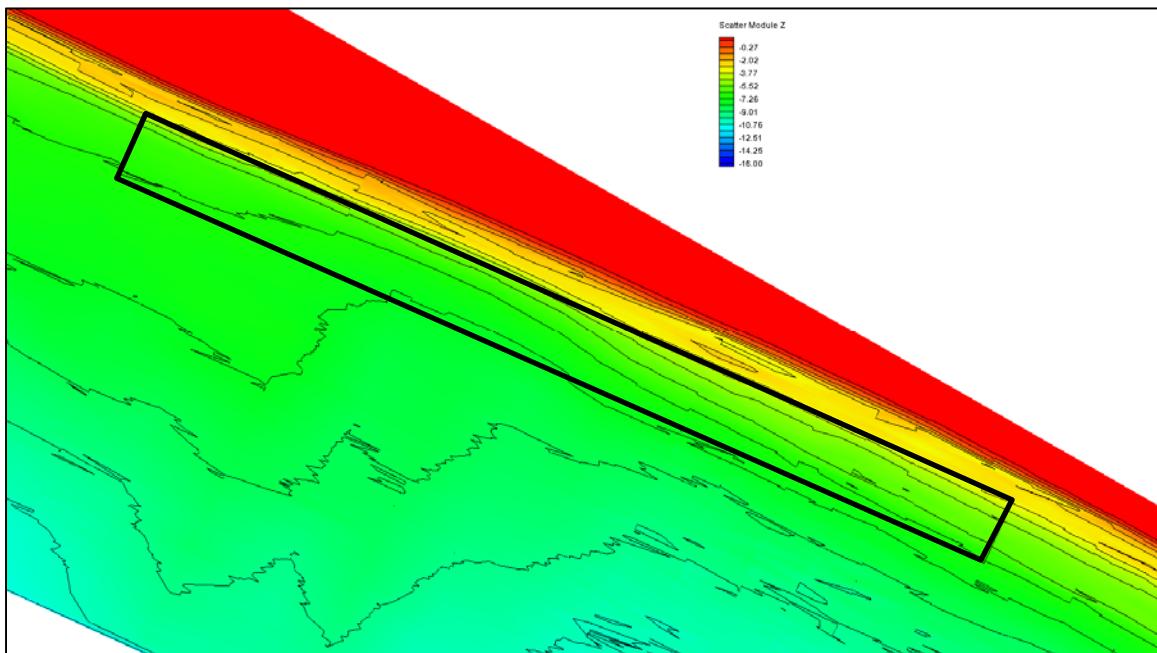


Figure 45. Contour Map of the Project Area Pre-Construction May 2009.

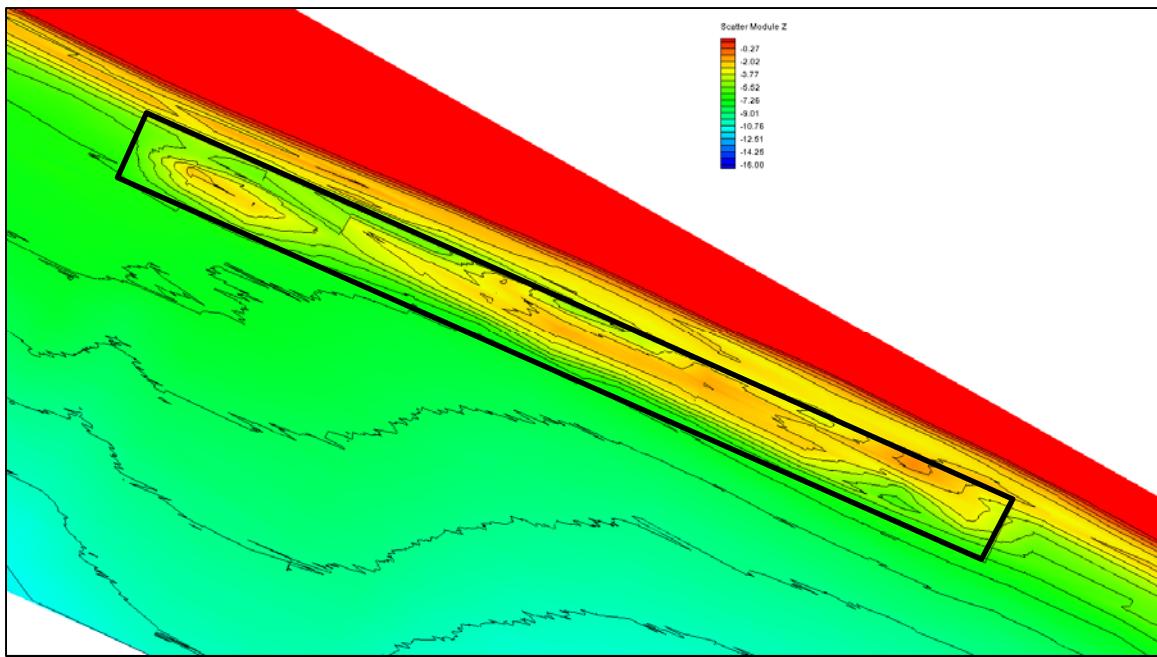


Figure 46. Contour Map of the Project Area Post Construction October 2009.

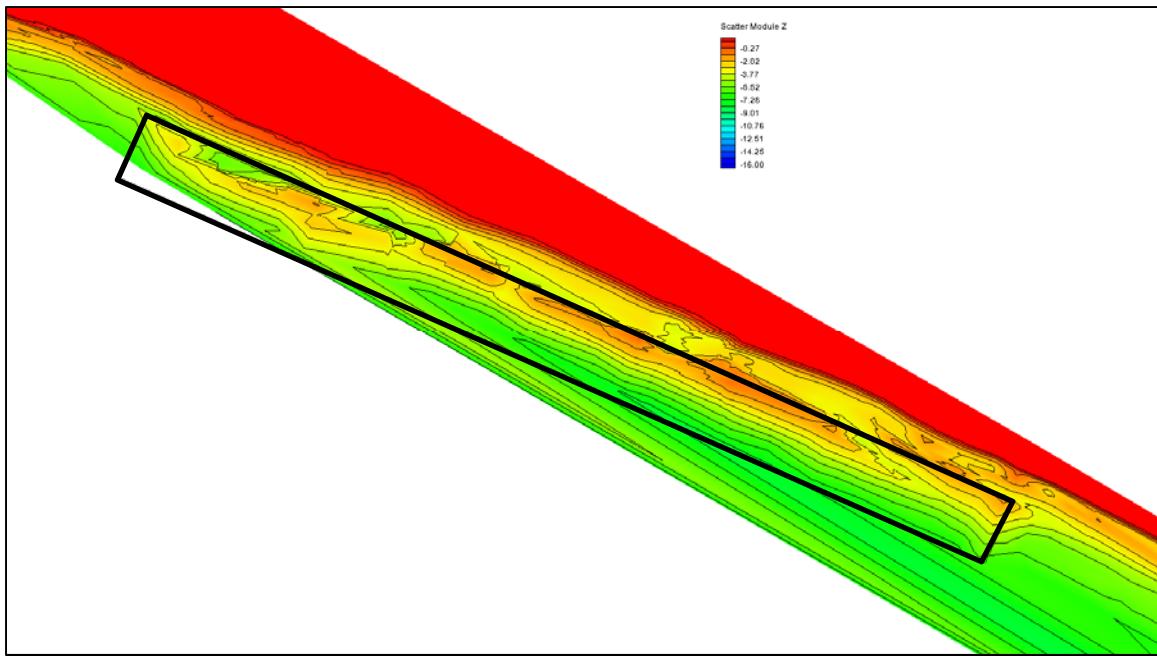


Figure 47. Contour Map of the Project Area April 2010.

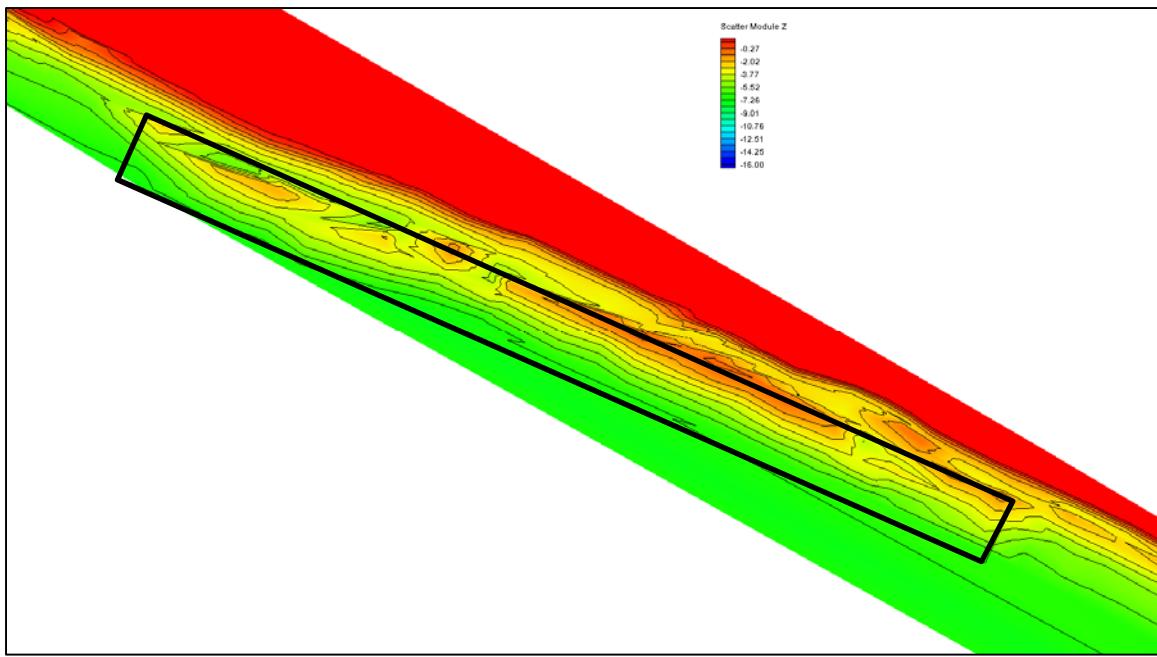


Figure 48. Contour Map of the Project Area October 2010.

Because the Fort Myers Beach berm was placed within the depth of closure as defined by Hallermeier (1981), it has migrated onshore as Hands and Allison's (1991) study suggested. The most rapid onshore migration happened within the first 6 months of placement, as the system was attempting to reach equilibrium. During the second 6 months, the berm still migrated onshore, but at a reduced rate.

CONCLUSIONS

Sedimentological data from the artificial berm and the surrounding area at Fort Myers Beach show that the study area is mostly composed of well sorted, fine sand. High percentages of mud (up to 40 %) were found offshore of the control area southeast off the artificial berm. In the berm project area, highest percentages of mud were found in the trough landward of the berm, where the wave energy is relatively low. High mud percentages were also found offshore. The coarsest sediments with corresponding highest percentage of carbonates were found in the swash zone, as expected, but also at the landward toe of the berm. This trend of sediment distribution may indicate a selective transport mechanism moving coarser sediment from the berm onshore, and finer sediment offshore, however, it could also be related native beach prior to berm placement. This trend is also supported by the overall coarsening of the berm based on the comparison of mud percentages in surface sediment samples and that averaged from the dredge area.

First year morphological changes of the artificial berm and shoreline were quantified based on surveys from USACE and USF. Based on existing classification schemes, the Fort Myers Beach berm can be classified as an active/feeder berm. As the system was attempting to reach a state of equilibrium after the perturbation of the placement, the berm migrated onshore rapidly during

the first 6 months, moving landward up to 200 ft, and gaining elevation up to 2 ft. During the second 6 months, the berm continued to migrate onshore, but at a much reduced rate. Berm height, measured from the bottom of the trough to the top of the crest, remained largely stable during the first year; however the shape of the berm changed from a symmetrical form to an asymmetrical form with a steep landward slope, illustrating the morphology of an onshore moving bar. In addition to moving onshore, the berm has spread laterally approximately 450 ft, as calculated from the survey data. Berm morphology in the longshore direction immediately after placement was highly variable, and remained variable throughout the study period. Gaps in the berm created during construction were dynamic and may be maintained by rip currents during energetic conditions. Most of the gaps appear to be at an oblique angle to the shoreline, creating a morphology resembling a two bar system when viewed in a cross shore survey profile. A substantial gap formed at beach profile FMB 35 during the second 6 months; however it is suspected that this gap was opened by anthropogenic activities (as was unofficially confirmed by a beach attendee). No clear trend in volume change within the project area can be identified. Sediment transport appears to be cross-shore dominated since most of the volume change in the profile involved sediment moving from the beach/nearshore to the bar or vice versa. There seems to be a weak trend of northward longshore sediment transport, but placement of the berm may have slowed the longshore sediment transport in the study area, due to its function as a submerged breakwater. A salient has formed on the northern portion of the berm project area.

As nearshore berms are becoming an increasingly popular option for disposal of dredged material, it is important to understand the evolution of this type of nourishment. Findings from this study and future studies will contribute to the understanding of the behavior of nearshore berms, as well as their influence on the surrounding beach morphology and sediment characteristics.

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APPENDICES

Appendix A. Conversion from Meters to Feet

For the purpose of this study, the following conversion factor between meters and feet was used: 1 meter = 3.2808399 feet.

Appendix B. Grain Size Analysis Data

The following appendix contains grain size analysis data for each of the samples collected. Percentages of gravel, sand, mud, and carbonates are given. Mean grain size (x_ϕ) and sorting (σ_ϕ) were calculated using the moment method and recorded in the tables, along with their corresponding size and sorting class according to the Wentworth scale. Both wet and dry color is recorded using the Munsell Color Chart. The dry color is recorded for the coarse fraction only. Sample lines FMB 3, FMB 6, FMB 9, FMB 13, FMB 53, and FMB 56 are within the control areas outside of the berm project area. Sample lines FMB17, FMB 22, FMB 28, FMB 35, and FMB 46 are located within the berm project area. Sample locations vary, however, generally in the control areas beginning with sample 1, surface sediment samples were taken at approximately the toe of the dune (where present), backbeach, high tide line, mean sea level, low tide line, 2 ft water depth, 4 ft water depth, 6 ft water depth, and 8 ft water depth relative to NAVD88. In the berm area, surface sediment samples were taken at approximately the toe of the dune (where present), backbeach, high tide line, mean seal level, low tide line, roughly in the middle between the berm and the shoreline, landward toe of the berm, midway up the landward slope of the berm, top of the berm, and seaward approximately every 100 ft until about 8 ft water depth, and at 8 ft water depth relative to NAVD88. Figure B1 illustrates the locations of the sample lines.

Appendix B. (Continued)

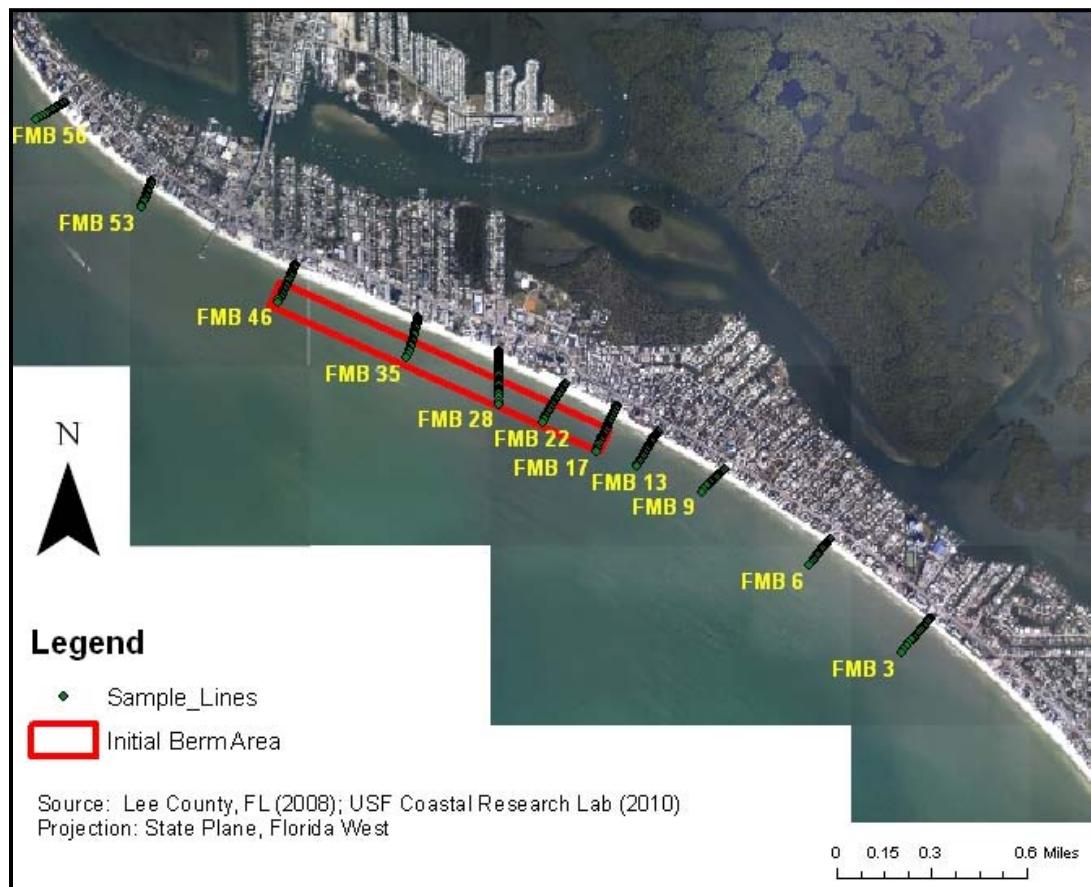


Figure B1. Locations of Sediment Sampling Transects.

Appendix B. (Continued)

Table B1. FMB 3 Grain Size Analysis Data.

FMB 3-1	% Gravel	0.00	$x\Phi =$	2.71	$\sigma\Phi =$	0.38
	% Sand	99.68	Size:	Fine Sand	Sorting:	Well sorted
	% Mud	0.32				
	% Carbonates	8.82				
FMB 3-2	% Gravel	0.00	$x\Phi =$	2.73	$\sigma\Phi =$	0.36
	% Sand	99.57	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.43				
	% Carbonates	3.23				
FMB 3-3	% Gravel	2.34	$x\Phi =$	2.42	$\sigma\Phi =$	1.12
	% Sand	96.47	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	1.19				
	% Carbonates	16.20				
FMB 3-4	% Gravel	16.08	$x\Phi =$	1.21	$\sigma\Phi =$	1.94
	% Sand	82.68	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	1.24				
	% Carbonates	49.78				
FMB 3-5	% Gravel	0.55	$x\Phi =$	2.85	$\sigma\Phi =$	0.67
	% Sand	97.66	Size:	Fine Sand	Sorting:	Moderately Well sorted
	% Mud	1.79				
	% Carbonates	7.18				
FMB 3-6	% Gravel	4.55	$x\Phi =$	2.51	$\sigma\Phi =$	1.33
	% Sand	93.97	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	1.48				
	% Carbonates	15.46				
FMB 3-7	% Gravel	0.02	$x\Phi =$	3.30	$\sigma\Phi =$	0.32
	% Sand	95.57	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	4.41				
	% Carbonates	3.76				
FMB 3-8	% Gravel	0.00	$x\Phi =$	3.79	$\sigma\Phi =$	0.38
	% Sand	58.60	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	41.40				
	% Carbonates	20.39				
FMB 3-9	% Gravel	0.30	$x\Phi =$	3.53	$\sigma\Phi =$	0.76
	% Sand	60.69	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	39.01				
	% Carbonates	12.84				

**Color not recorded for FMB 3 samples.

Appendix B. (Continued)

Table B2. FMB 6 Grain Size Analysis Data.

FMB 6-1 **Lost**						
FMB 6-2	% Gravel	1.36	$x\Phi =$	2.70	$\sigma\Phi =$	0.75
	% Sand	98.58	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.07	Color:			
	% Carbonates	4.17	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 6-3	% Gravel	1.77	$x\Phi =$	2.57	$\sigma\Phi =$	0.94
	% Sand	97.44	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.79	Color:			
	% Carbonates	10.42	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 6-4	**Lost**					
FMB 6-5	% Gravel	17.73	$x\Phi =$	1.05	$\sigma\Phi =$	1.94
	% Sand	80.87	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	1.40	Color:			
	% Carbonates	52.83	Wet:	2.5Y 6/1	Dry:	2.5Y 8/1
FMB 6-6	**Lost**					
FMB 6-7	% Gravel	0.15	$x\Phi =$	3.21	$\sigma\Phi =$	0.39
	% Sand	96.62	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	3.23	Color:			
	% Carbonates	2.48	Wet:	5Y 4/1	Dry:	5Y 8/1
FMB 6-8	% Gravel	0.02	$x\Phi =$	3.61	$\sigma\Phi =$	0.41
	% Sand	79.98	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	20.00	Color:			
	% Carbonates	8.68	Wet:	5Y 6/2	Dry:	5Y 7/1
FMB 6-9	**Lost**					

Appendix B. (Continued)

Table B3. FMB 9 Grain Size Analysis Data.

FMB 9-1	% Gravel	0.00	$x\phi =$	2.77	$\sigma\phi =$	0.34
	% Sand	99.65	Size:	Fine Sand	Sorting:	Very Well Sorted
	% Mud	0.35	Color:			
	% Carbonates	1.28	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 9-2	% Gravel	0.26	$x\phi =$	2.73	$\sigma\phi =$	0.42
	% Sand	99.43	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.32	Color:			
	% Carbonates	2.39	Wet:	5Y 8/1	Dry:	2.5Y 8/1
FMB 9-3	% Gravel	1.75	$x\phi =$	2.69	$\sigma\phi =$	0.84
	% Sand	96.70	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	1.56	Color:			
	% Carbonates	7.06	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 9-4	% Gravel	9.13	$x\phi =$	1.58	$\sigma\phi =$	1.68
	% Sand	89.63	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	1.24	Color:			
	% Carbonates	39.32	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 9-5	% Gravel	25.20	$x\phi =$	1.14	$\sigma\phi =$	2.20
	% Sand	73.35	Size:	Medium Sand	Sorting:	Very Poorly Sorted
	% Mud	1.45	Color:			
	% Carbonates	44.08	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 9-6	% Gravel	0.17	$x\phi =$	3.00	$\sigma\phi =$	0.45
	% Sand	97.84	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	1.99	Color:			
	% Carbonates	2.58	Wet:	5Y 6/2	Dry:	2.5Y 8/1
FMB 9-7	% Gravel	0.06	$x\phi =$	3.22	$\sigma\phi =$	0.32
	% Sand	96.65	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	3.28	Color:			
	% Carbonates	1.92	Wet:	5Y 5/1	Dry:	2.5Y 8/1
FMB 9-8	% Gravel	0.00	$x\phi =$	3.36	$\sigma\phi =$	0.30
	% Sand	95.71	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	4.29	Color:			
	% Carbonates	2.49	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 9-9	% Gravel	0.00	$x\phi =$	3.53	$\sigma\phi =$	0.30
	% Sand	90.46	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	9.54	Color:			
	% Carbonates	4.81	Wet:	5Y 5/2	Dry:	2.5Y 8/1

Appendix B. (Continued)

Table B4. FMB 13 Grain Size Analysis Data.

FMB 13-1	% Gravel	0.16	$x\Phi=$	2.66	$\sigma\Phi=$	0.47
	% Sand	99.51	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.34	Color:			
	% Carbonates	2.75	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 13-2	% Gravel	4.39	$x\Phi=$	2.29	$\sigma\Phi=$	1.30
	% Sand	95.16	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.45	Color:			
	% Carbonates	13.33	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 13-3	% Gravel	3.24	$x\Phi=$	2.68	$\sigma\Phi=$	1.09
	% Sand	96.01	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.75	Color:			
	% Carbonates	6.56	Wet:	5Y 7/2	Dry:	5Y 8/1
FMB 13-4	% Gravel	9.71	$x\Phi=$	2.05	$\sigma\Phi=$	1.67
	% Sand	88.99	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	1.31	Color:			
	% Carbonates	23.70	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 13-5	% Gravel	22.54	$x\Phi=$	1.02	$\sigma\Phi=$	2.11
	% Sand	76.11	Size:	Medium Sand	Sorting:	Very Poorly Sorted
	% Mud	1.35	Color:			
	% Carbonates	47.62	Wet:	5Y 6/1	Dry:	2.5Y 8/1
FMB 13-6	% Gravel	0.11	$x\Phi=$	2.97	$\sigma\Phi=$	0.35
	% Sand	98.19	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	1.70	Color:			
	% Carbonates	1.73	Wet:	5Y 6/1	Dry:	2.5Y 8/1
FMB 13-7	% Gravel	0.06	$x\Phi=$	3.27	$\sigma\Phi=$	0.31
	% Sand	96.60	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	3.34	Color:			
	% Carbonates	1.36	Wet:	5Y 5/1	Dry:	2.5Y 8/1
FMB 13-8	% Gravel	0.27	$x\Phi=$	3.34	$\sigma\Phi=$	0.43
	% Sand	95.07	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	4.66	Color:			
	% Carbonates	2.32	Wet:	5Y 5/1	Dry:	2.5Y 8/1
FMB 13-9	% Gravel	0.05	$x\Phi=$	3.58	$\sigma\Phi=$	0.55
	% Sand	74.24	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	25.71	Color:			
	% Carbonates	8.36	Wet:	5Y 4/1	Dry:	5Y 7/1

Appendix B. (Continued)

Table B5. FMB 17 Grain Size Analysis Data.

FMB 17-1	% Gravel	0.59	$x\Phi=$	2.80	$\sigma\Phi=$	0.58
	% Sand	98.94	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.46	Color:			
	% Carbonates	1.76	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 17-2	% Gravel	0.99	$x\Phi=$	2.61	$\sigma\Phi=$	0.73
	% Sand	98.65	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.36	Color:			
	% Carbonates	6.27	Wet:	5Y 8/1	Dry:	2.5Y 8/1
FMB 17-3	% Gravel	4.78	$x\Phi=$	2.51	$\sigma\Phi=$	1.26
	% Sand	93.78	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	1.44	Color:			
	% Carbonates	11.50	Wet:	2.5Y 8/1	Dry:	2.5Y 8/1
FMB 17-4	% Gravel	5.77	$x\Phi=$	1.96	$\sigma\Phi=$	1.54
	% Sand	92.93	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	1.30	Color:			
	% Carbonates	30.67	Wet:	5Y 8/2	Dry:	2.5Y 8/1
FMB 17-5	% Gravel	21.70	$x\Phi=$	1.00	$\sigma\Phi=$	2.04
	% Sand	76.62	Size:	Medium Sand	Sorting:	Very Poorly Sorted
	% Mud	1.68	Color:			
	% Carbonates	53.96	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 17-6	% Gravel	0.81	$x\Phi=$	2.96	$\sigma\Phi=$	0.69
	% Sand	97.38	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	1.81	Color:			
	% Carbonates	3.36	Wet:	2.5Y 6/2	Dry:	5Y 8/1
FMB 17-7	% Gravel	0.26	$x\Phi=$	3.15	$\sigma\Phi=$	0.51
	% Sand	96.75	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	2.99	Color:			
	% Carbonates	3.32	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 17-8	% Gravel	1.38	$x\Phi=$	2.64	$\sigma\Phi=$	0.87
	% Sand	96.92	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	1.70	Color:			
	% Carbonates	4.31	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 17-9	% Gravel	0.94	$x\Phi=$	2.71	$\sigma\Phi=$	0.85
	% Sand	97.20	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	1.86	Color:			
	% Carbonates	4.83	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 17-10	% Gravel	3.27	$x\Phi=$	2.48	$\sigma\Phi=$	1.27
	% Sand	93.54	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	3.19	Color:			
	% Carbonates	10.47	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 17-11	% Gravel	8.06	$x\Phi=$	1.34	$\sigma\Phi=$	1.47
	% Sand	90.01	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	1.93	Color:			
	% Carbonates	29.49	Wet:	5Y 7/2	Dry:	5Y 8/1

Appendix B. (Continued)

Table B6. FMB 22 Grain Size Analysis Data.

FMB 22-1	% Gravel	0.14	$x\phi =$	2.70	$\sigma\phi =$	0.46
	% Sand	99.58	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.27	Color:			
	% Carbonates	2.61	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 22-2	% Gravel	0.03	$x\phi =$	2.59	$\sigma\phi =$	0.44
	% Sand	99.71	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.26	Color:			
	% Carbonates	2.01	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 22-3	% Gravel	0.00	$x\phi =$	2.95	$\sigma\phi =$	0.36
	% Sand	98.48	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	1.52	Color:			
	% Carbonates	4.48	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 22-4	% Gravel	15.07	$x\phi =$	1.69	$\sigma\phi =$	2.03
	% Sand	83.81	Size:	Medium Sand	Sorting:	Very Poorly Sorted
	% Mud	1.12	Color:			
	% Carbonates	35.09	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 22-5	% Gravel	4.54	$x\phi =$	2.73	$\sigma\phi =$	1.23
	% Sand	94.04	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	1.42	Color:			
	% Carbonates	9.59	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 22-6	% Gravel	0.10	$x\phi =$	3.02	$\sigma\phi =$	0.34
	% Sand	99.02	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	0.88	Color:			
	% Carbonates	2.12	Wet:	5Y 7/2	Dry:	5Y 8/1
FMB 22-7	% Gravel	0.00	$x\phi =$	3.02	$\sigma\phi =$	0.35
	% Sand	97.08	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	2.92	Color:			
	% Carbonates	1.87	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 22-8	% Gravel	0.07	$x\phi =$	3.55	$\sigma\phi =$	0.59
	% Sand	58.12	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	41.81	Color:			
	% Carbonates	6.75	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 22-9	% Gravel	0.98	$x\phi =$	2.79	$\sigma\phi =$	0.84
	% Sand	90.71	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	8.31	Color:			
	% Carbonates	5.22	Wet:	5Y 4/2	Dry:	5Y 8/1
FMB 22-10	% Gravel	1.79	$x\phi =$	2.78	$\sigma\phi =$	0.88
	% Sand	96.69	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	1.52	Color:			
	% Carbonates	3.59	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 22-11	% Gravel	0.98	$x\phi =$	3.13	$\sigma\phi =$	0.68
	% Sand	95.22	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	3.80	Color:			
	% Carbonates	3.58	Wet:	5Y 7/1	Dry:	5Y 8/1

Appendix B. (Continued)

Table B7. FMB 28 Grain Size Analysis Data.

FMB 28-1	% Gravel	0.13	xΦ=	2.80	σΦ=	0.44
	% Sand	99.44	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.42	Color:			
	% Carbonates	2.13	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 28-2	% Gravel	0.00	xΦ=	2.82	σΦ=	0.32
	% Sand	99.43	Size:	Fine Sand	Sorting:	Very Well Sorted
	% Mud	0.57	Color:			
	% Carbonates	1.30	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 28-3	% Gravel	0.11	xΦ=	2.93	σΦ=	0.48
	% Sand	98.81	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	1.07	Color:			
	% Carbonates	5.19	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 28-4	% Gravel	4.48	xΦ=	2.48	σΦ=	1.43
	% Sand	94.56	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.96	Color:			
	% Carbonates	21.29	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 28-5	% Gravel	0.75	xΦ=	2.97	σΦ=	0.65
	% Sand	97.57	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	1.68	Color:			
	% Carbonates	7.05	Wet:	2.5Y 7/1	Dry:	5Y 8/1
FMB 28-6	% Gravel	0.34	xΦ=	3.14	σΦ=	0.58
	% Sand	95.63	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	4.02	Color:			
	% Carbonates	9.42	Wet:	5Y 4/1	Dry:	2.5Y 8/1
FMB 28-7	% Gravel	0.02	xΦ=	3.10	σΦ=	0.31
	% Sand	98.27	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	1.71	Color:			
	% Carbonates	1.42	Wet:	5Y 6/1	Dry:	2.5Y 8/1
FMB 28-8	% Gravel	3.96	xΦ=	1.87	σΦ=	1.25
	% Sand	94.92	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	1.11	Color:			
	% Carbonates	16.25	Wet:	5Y 4/1	Dry:	5Y 8/1
FMB 28-9	% Gravel	1.54	xΦ=	2.36	σΦ=	0.92
	% Sand	98.03	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.42	Color:			
	% Carbonates	9.37	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 28-10	% Gravel	2.27	xΦ=	2.78	σΦ=	1.03
	% Sand	96.31	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	1.42	Color:			
	% Carbonates	8.29	Wet:	2.5Y 7/1	Dry:	2.5Y 8/1
FMB 28-11	% Gravel	1.80	xΦ=	3.04	σΦ=	1.05
	% Sand	93.00	Size:	Very Fine Sand	Sorting:	Poorly Sorted
	% Mud	5.20	Color:			
	% Carbonates	4.95	Wet:	5Y 5/1	Dry:	5Y 8/1

Appendix B. (Continued)

Table B8. FMB 35 Grain Size Analysis Data.

FMB 35-1	% Gravel	0.05	$x\Phi =$	2.79	$\sigma\Phi =$	0.37
	% Sand	99.86	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.09	Color:			
	% Carbonates	1.88	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 35-2	% Gravel	0.54	$x\Phi =$	2.72	$\sigma\Phi =$	0.58
	% Sand	99.31	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.15	Color:			
	% Carbonates	2.98	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 35-3	% Gravel	0.18	$x\Phi =$	2.95	$\sigma\Phi =$	0.44
	% Sand	99.51	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.31	Color:			
	% Carbonates	3.01	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 35-4	% Gravel	4.34	$x\Phi =$	2.44	$\sigma\Phi =$	1.41
	% Sand	95.25	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.41	Color:			
	% Carbonates	17.86	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 35-5	% Gravel	2.86	$x\Phi =$	2.72	$\sigma\Phi =$	1.12
	% Sand	96.64	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.50	Color:			
	% Carbonates	10.60	Wet:	5Y 6/1	Dry:	2.5Y 8/1
FMB 35-6	% Gravel	0.13	$x\Phi =$	3.04	$\sigma\Phi =$	0.45
	% Sand	98.69	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	1.18	Color:			
	% Carbonates	2.90	Wet:	5Y 6/2	Dry:	5Y 8/1
FMB 35-7	% Gravel	0.68	$x\Phi =$	2.82	$\sigma\Phi =$	0.74
	% Sand	98.27	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	1.05	Color:			
	% Carbonates	5.45	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 35-8	% Gravel	2.85	$x\Phi =$	2.20	$\sigma\Phi =$	1.04
	% Sand	96.92	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.23	Color:			
	% Carbonates	9.36	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 35-9	% Gravel	3.27	$x\Phi =$	2.54	$\sigma\Phi =$	1.11
	% Sand	96.22	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.50	Color:			
	% Carbonates	7.90	Wet:	5Y 7/2	Dry:	5Y 8/1
FMB 35-10	% Gravel	2.37	$x\Phi =$	2.46	$\sigma\Phi =$	1.07
	% Sand	96.25	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	1.38	Color:			
	% Carbonates	9.54	Wet:	5Y 7/1	Dry:	5Y 8/1

Appendix B. (Continued)

Table B9. FMB 46 Grain Size Analysis Data.

FMB 46-1	% Gravel	0.37	$x\phi =$	2.68	$\sigma\phi =$	0.59
	% Sand	99.47	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.16	Color:			
	% Carbonates	3.32	Wet:	2.5Y 7/1	Dry:	2.5Y 8/1
FMB 46-2	% Gravel	0.23	$x\phi =$	2.69	$\sigma\phi =$	0.50
	% Sand	99.65	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.12	Color:			
	% Carbonates	2.52	Wet:	2.5Y 7/1	Dry:	2.5Y 8/1
FMB 46-3	% Gravel	0.37	$x\phi =$	2.48	$\sigma\phi =$	0.70
	% Sand	99.34	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.28	Color:			
	% Carbonates	6.30	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 46-4	% Gravel	12.93	$x\phi =$	1.65	$\sigma\phi =$	1.77
	% Sand	87.00	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	0.07	Color:			
	% Carbonates	27.83	Wet:	2.5Y 5/1	Dry:	5Y 8/1
FMB 46-5	% Gravel	2.63	$x\phi =$	2.50	$\sigma\phi =$	1.12
	% Sand	97.04	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.34	Color:			
	% Carbonates	7.72	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 46-6	% Gravel	0.00	$x\phi =$	3.14	$\sigma\phi =$	0.34
	% Sand	99.19	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	0.81	Color:			
	% Carbonates	2.52	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 46-7	% Gravel	0.36	$x\phi =$	3.16	$\sigma\phi =$	0.50
	% Sand	98.72	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	0.91	Color:			
	% Carbonates	2.87	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 46-8	% Gravel	0.82	$x\phi =$	2.66	$\sigma\phi =$	0.68
	% Sand	98.75	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.43	Color:			
	% Carbonates	4.36	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 46-9	% Gravel	0.11	$x\phi =$	2.94	$\sigma\phi =$	0.56
	% Sand	98.02	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	1.87	Color:			
	% Carbonates	2.68	Wet:	2.5Y 5/2	Dry:	5Y 8/1

Appendix B. (Continued)

Table B10. FMB 53 Grain Size Analysis Data.

FMB 53-1	% Gravel	0.16	$x\phi =$	2.64	$\sigma\phi =$	0.51
	% Sand	99.81	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.03	Color:			
	% Carbonates	2.58	Wet:	2.5Y 6/1	Dry:	2.5Y 8/1
FMB 53-2	% Gravel	0.00	$x\phi =$	2.79	$\sigma\phi =$	0.37
	% Sand	99.94	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.06	Color:			
	% Carbonates	1.54	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 53-3	% Gravel	0.04	$x\phi =$	2.77	$\sigma\phi =$	0.54
	% Sand	99.66	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.30	Color:			
	% Carbonates	3.18	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 53-4	% Gravel	0.14	$x\phi =$	2.76	$\sigma\phi =$	0.53
	% Sand	99.50	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.37	Color:			
	% Carbonates	3.14	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 53-5	% Gravel	2.36	$x\phi =$	2.54	$\sigma\phi =$	1.03
	% Sand	97.14	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.50	Color:			
	% Carbonates	9.11	Wet:	5Y 7/2	Dry:	5Y 8/1
FMB 53-6	% Gravel	0.72	$x\phi =$	2.86	$\sigma\phi =$	0.65
	% Sand	98.78	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.50	Color:			
	% Carbonates	2.66	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 53-7	% Gravel	0.09	$x\phi =$	3.07	$\sigma\phi =$	0.44
	% Sand	98.98	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	0.93	Color:			
	% Carbonates	1.63	Wet:	5Y 6/2	Dry:	5Y 8/1
FMB 53-8	% Gravel	0.31	$x\phi =$	3.10	$\sigma\phi =$	0.56
	% Sand	98.58	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	1.12	Color:			
	% Carbonates	2.15	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 53-9	% Gravel	0.00	$x\phi =$	2.94	$\sigma\phi =$	0.53
	% Sand	97.97	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	2.03	Color:			
	% Carbonates	1.81	Wet:	5Y 4/1	Dry:	5Y 8/1

Appendix B. (Continued)

Table B11. FMB 56 Grain Size Analysis Data.

FMB 56-1	% Gravel	0.20	$x\Phi =$	2.70	$\sigma\Phi =$	0.50
	% Sand	99.66	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.14	Color:			
	% Carbonates	2.48	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 56-2	% Gravel	0.29	$x\Phi =$	2.64	$\sigma\Phi =$	0.56
	% Sand	99.52	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.19	Color:			
	% Carbonates	3.03	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 56-3	% Gravel	0.19	$x\Phi =$	2.74	$\sigma\Phi =$	0.44
	% Sand	99.68	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.13	Color:			
	% Carbonates	3.40	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 56-4	% Gravel	0.98	$x\Phi =$	2.38	$\sigma\Phi =$	0.79
	% Sand	98.80	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.22	Color:			
	% Carbonates	5.46	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 56-5	% Gravel	0.79	$x\Phi =$	2.84	$\sigma\Phi =$	0.59
	% Sand	98.95	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.26	Color:			
	% Carbonates	2.02	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 56-6	% Gravel	1.46	$x\Phi =$	2.90	$\sigma\Phi =$	0.77
	% Sand	98.08	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.45	Color:			
	% Carbonates	3.18	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 56-7	% Gravel	0.03	$x\Phi =$	2.94	$\sigma\Phi =$	0.47
	% Sand	99.00	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.97	Color:			
	% Carbonates	1.42	Wet:	5Y 6/2	Dry:	5Y 8/2

Appendix C. Grain Size Distributions

The follow appendix includes grain size distribution charts of representative samples from each sample profiles. Grain size is recorded as phi, which can be related to mm by the equation

$$d = 2^{-\phi} \quad (14)$$

where d is the diameter of the grain in mm. Refer to Figure C1 for the sampling transect locations.

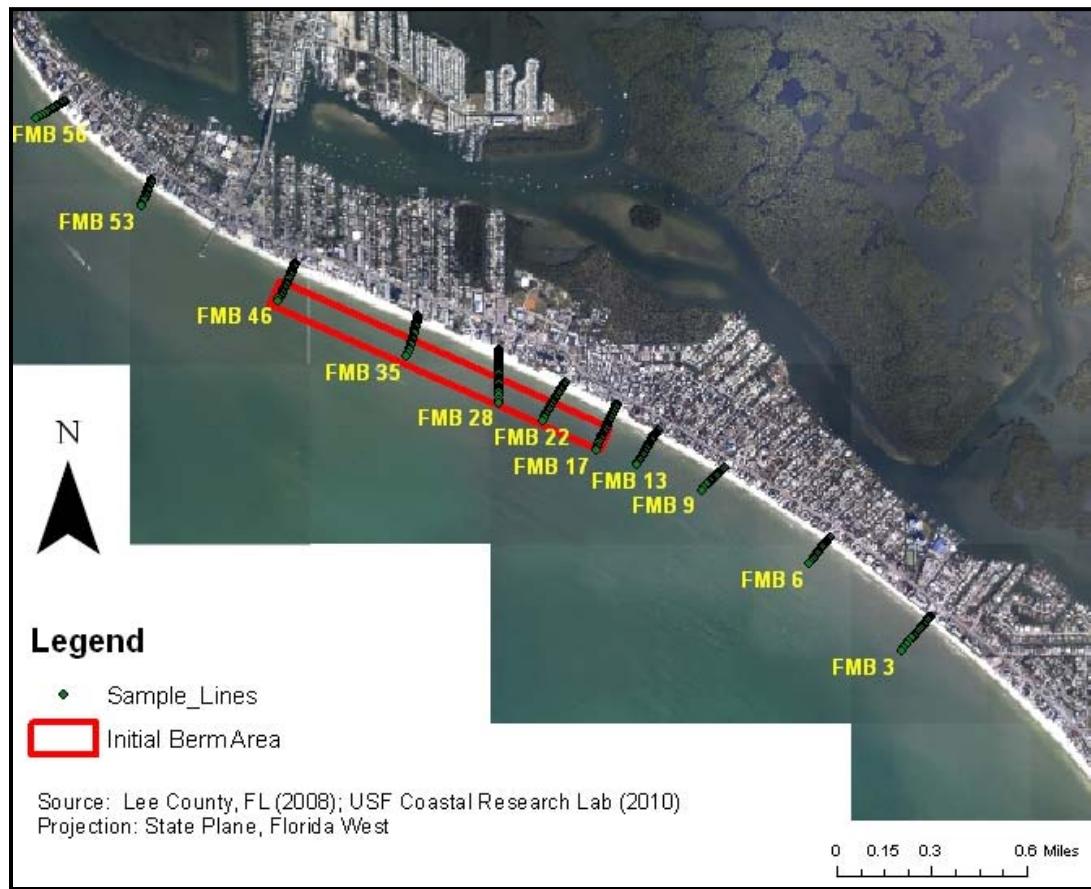


Figure C1. Locations of Sediment Sampling Transects.

Appendix C. (Continued)

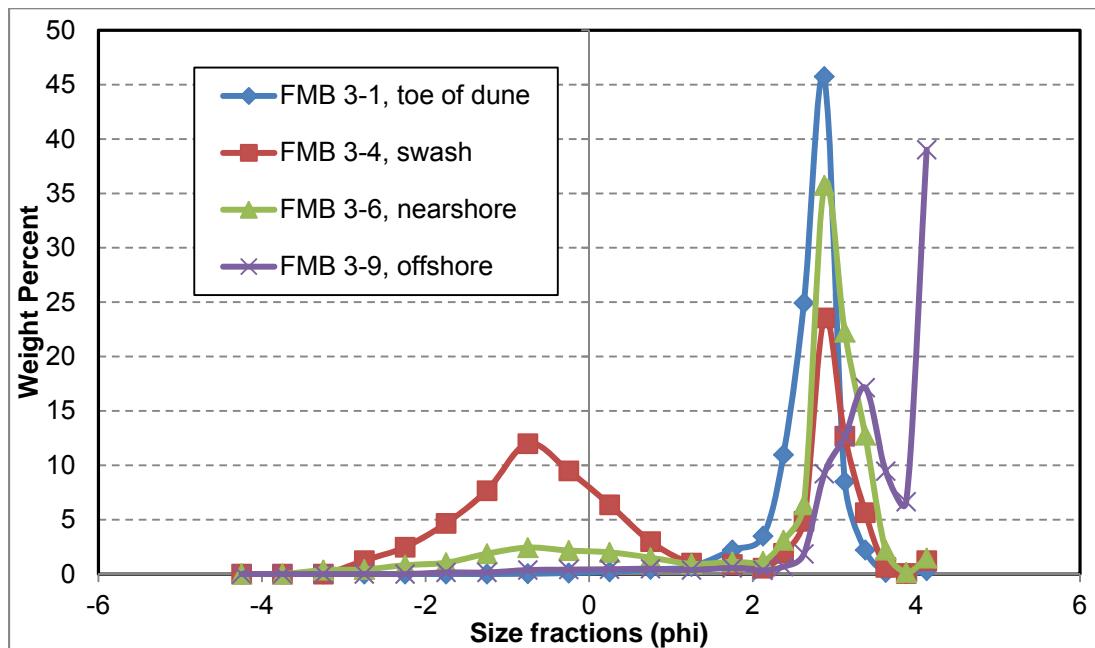


Figure C2. Grain Size Distribution at FMB 3.

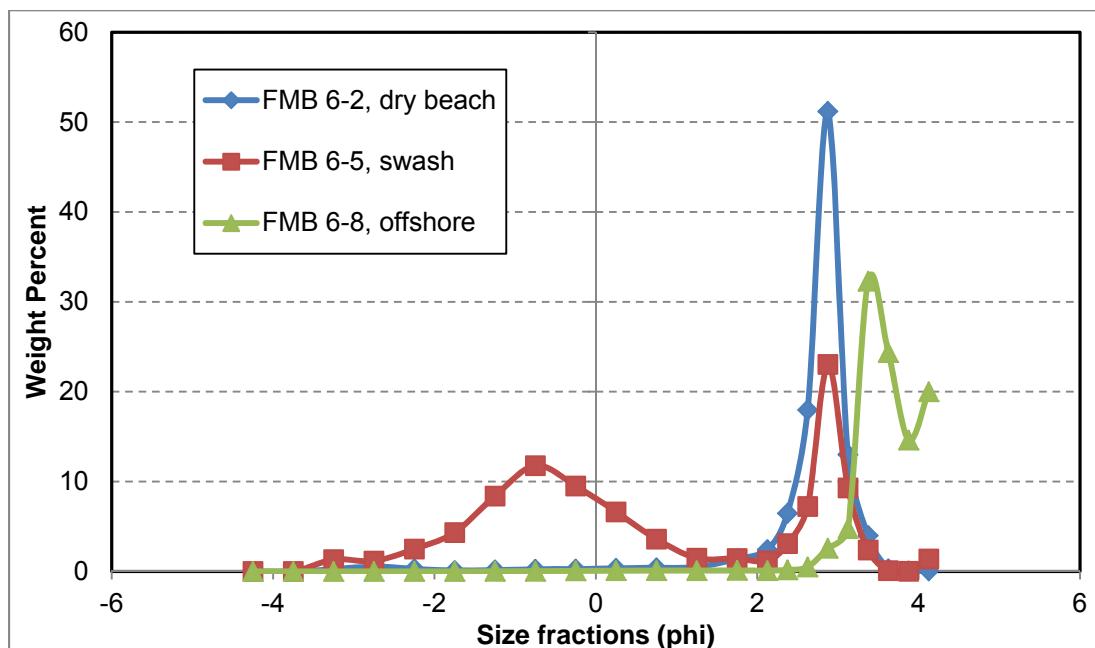


Figure C3. Grain Size Distribution at FMB 6.

Appendix C. (Continued)

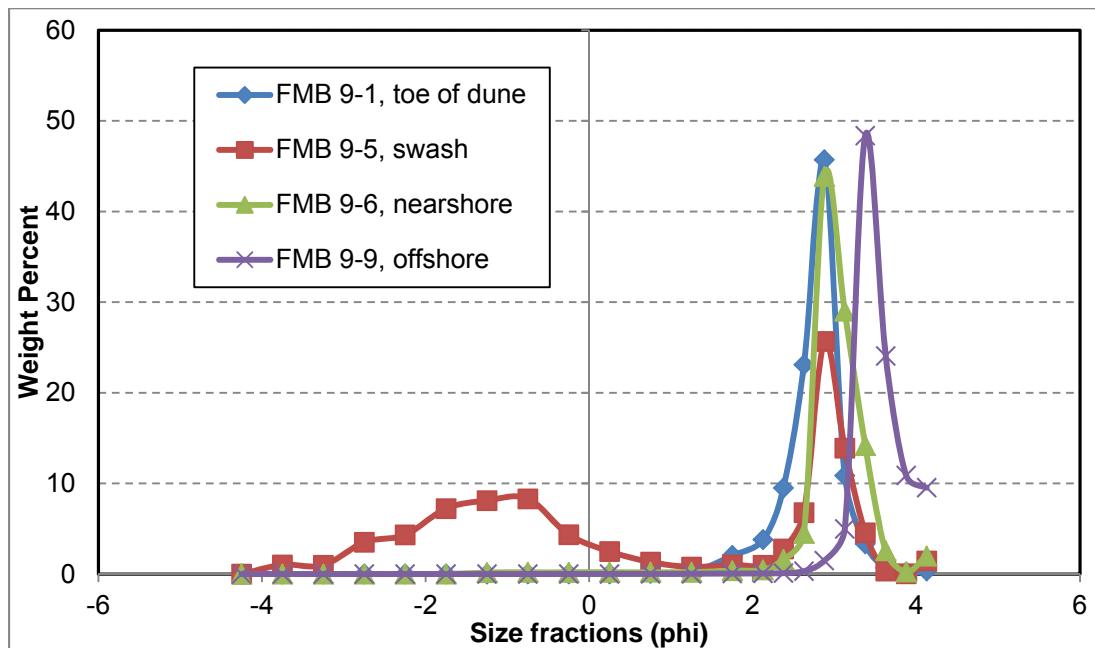


Figure C4. Grain Size Distribution at FMB 9.

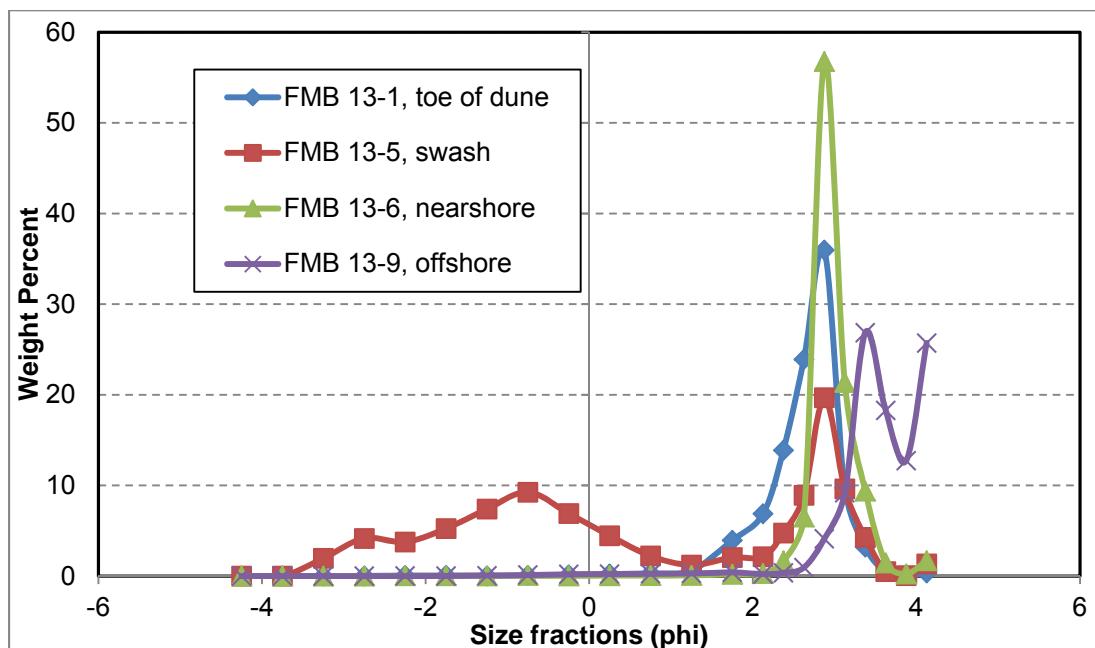


Figure C5. Grain Size Distribution at FMB 13

Appendix C. (Continued)

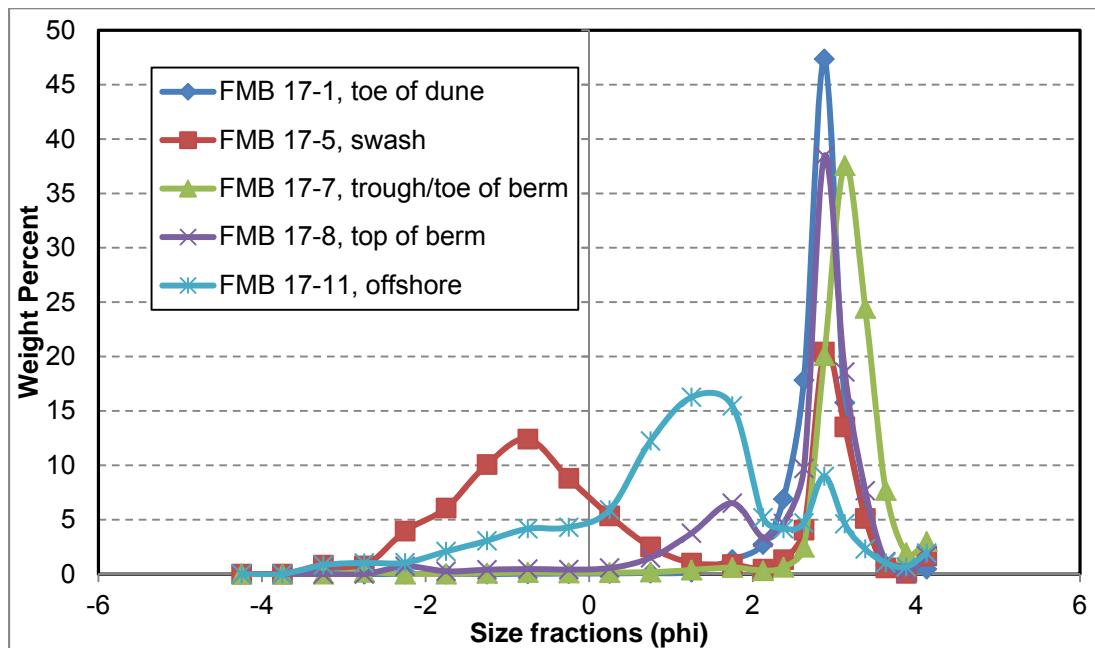


Figure C6. Grain Size Distribution at FMB 17.

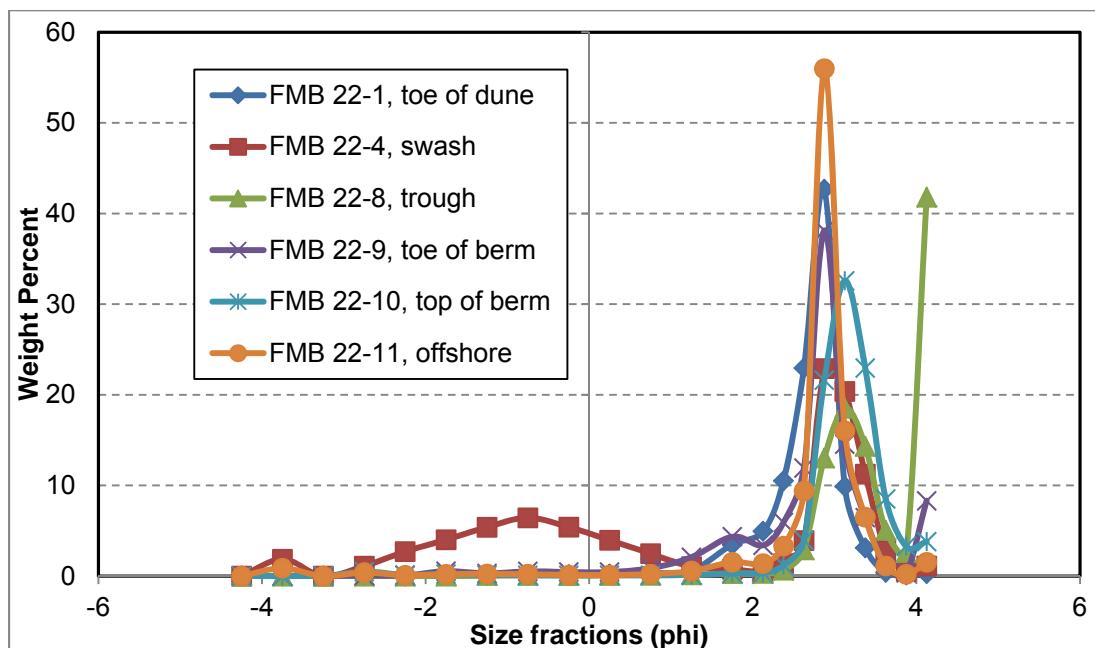


Figure C7. Grain Size Distribution at FMB 22.

Appendix C. (Continued)

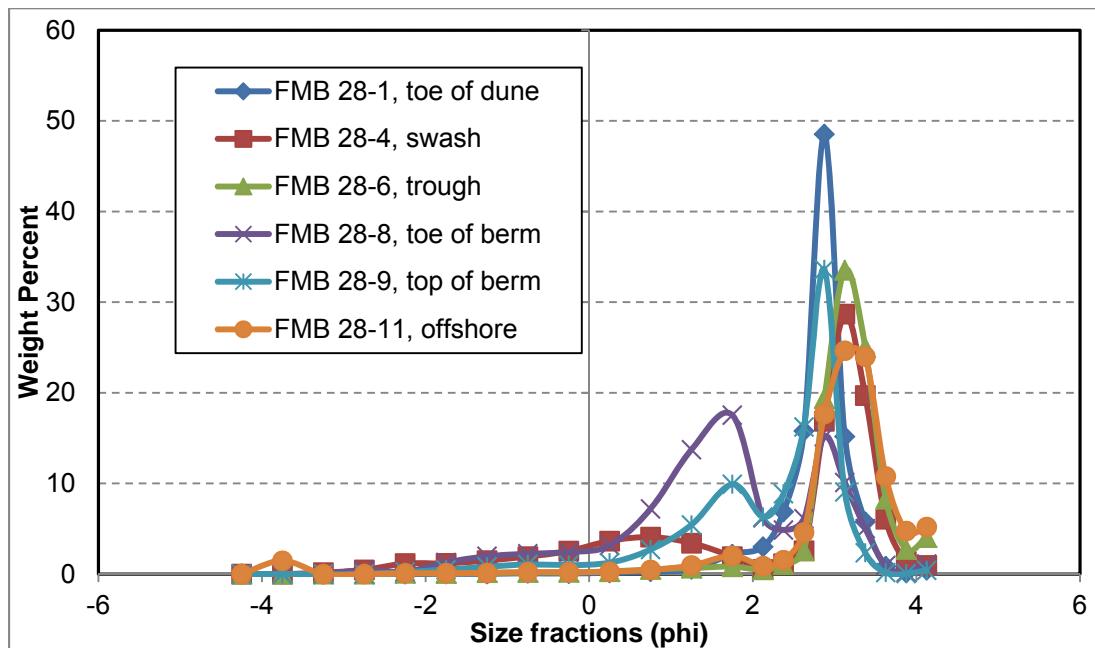


Figure C8. Grain Size Distribution at FMB 28.

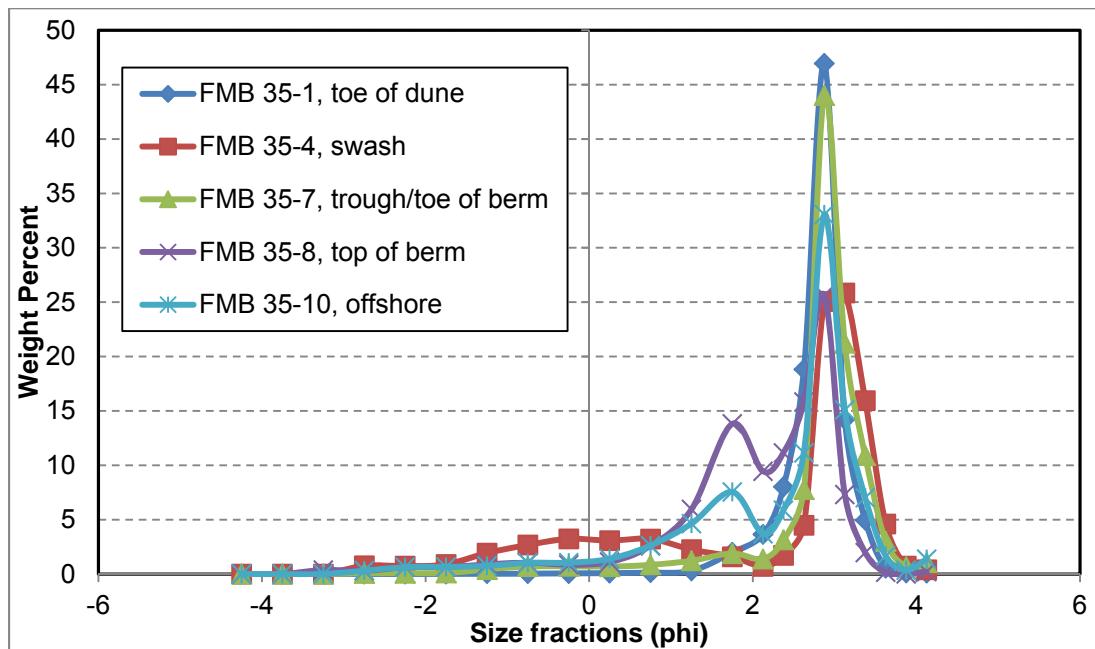


Figure C9. Grain Size Distribution at FMB 35.

Appendix C. (Continued)

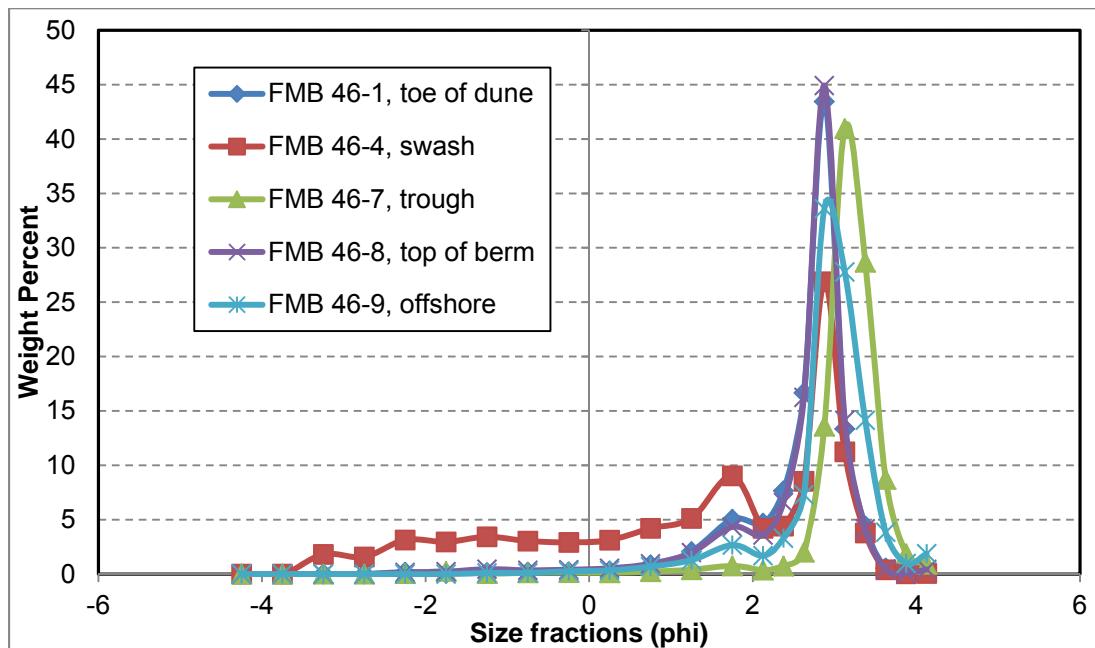


Figure C10. Grain Size Distribution at FMB 46.

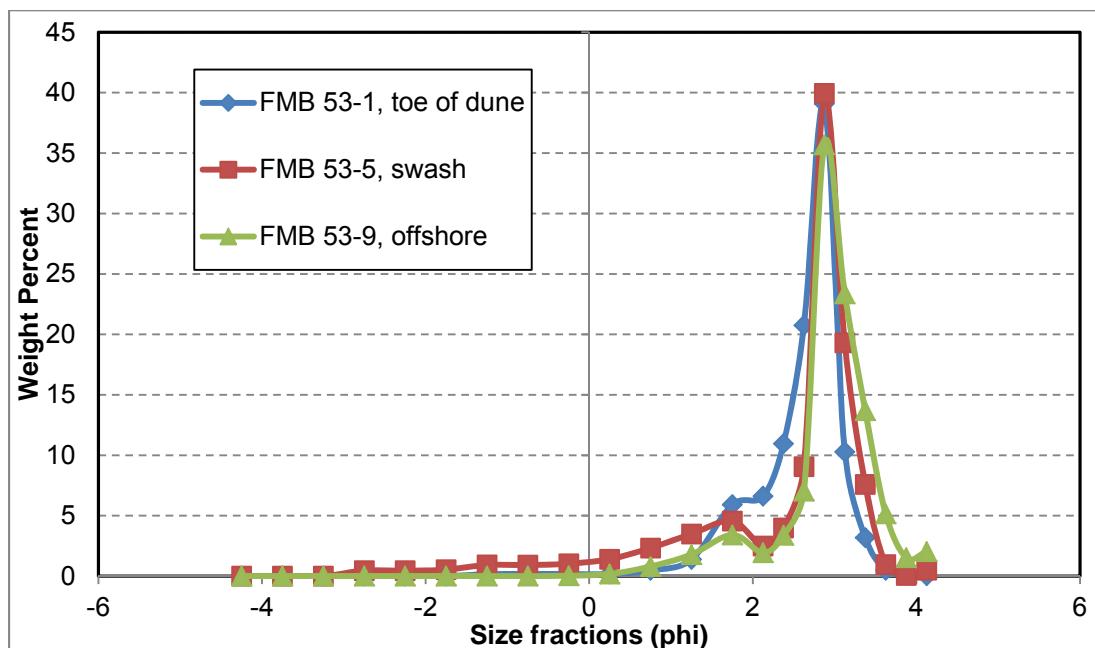


Figure C11. Grain Size Distribution at FMB 53.

Appendix C. (Continued)

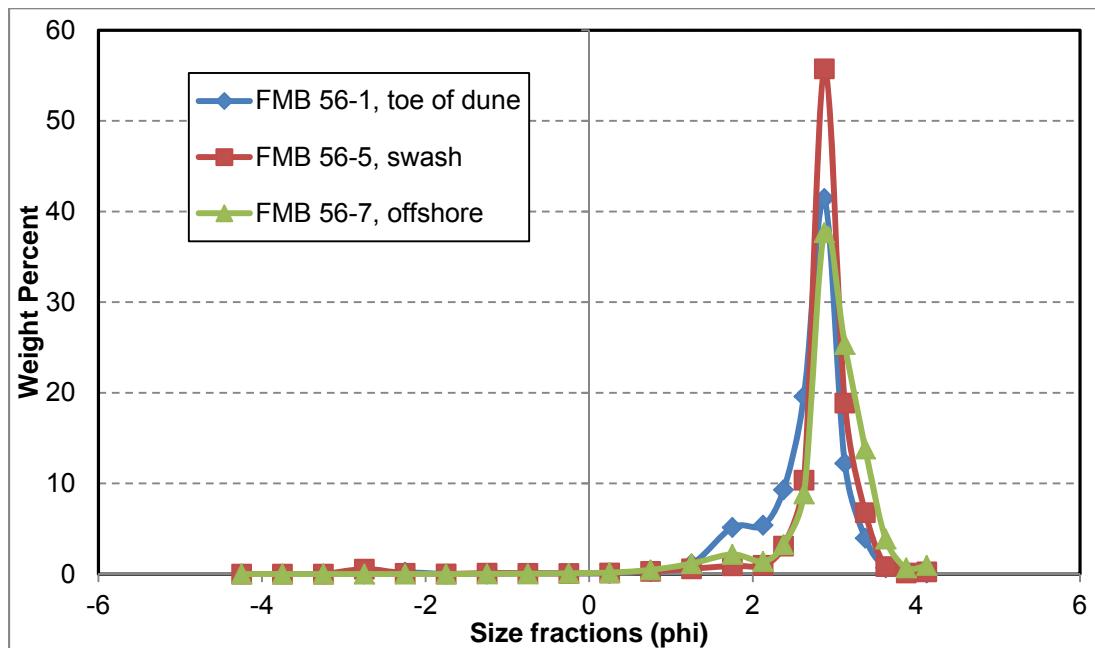


Figure C12. Grain Size Distribution at FMB 56.

Appendix D. Sediment Sample Locations with Mud Percentages

Appendix D illustrates the beach profile of each of the sample lines, with the sample locations indicated by red squares. Percentages of mud in the samples are given next to each sample location. Figure D1 shows the sampling transect locations.

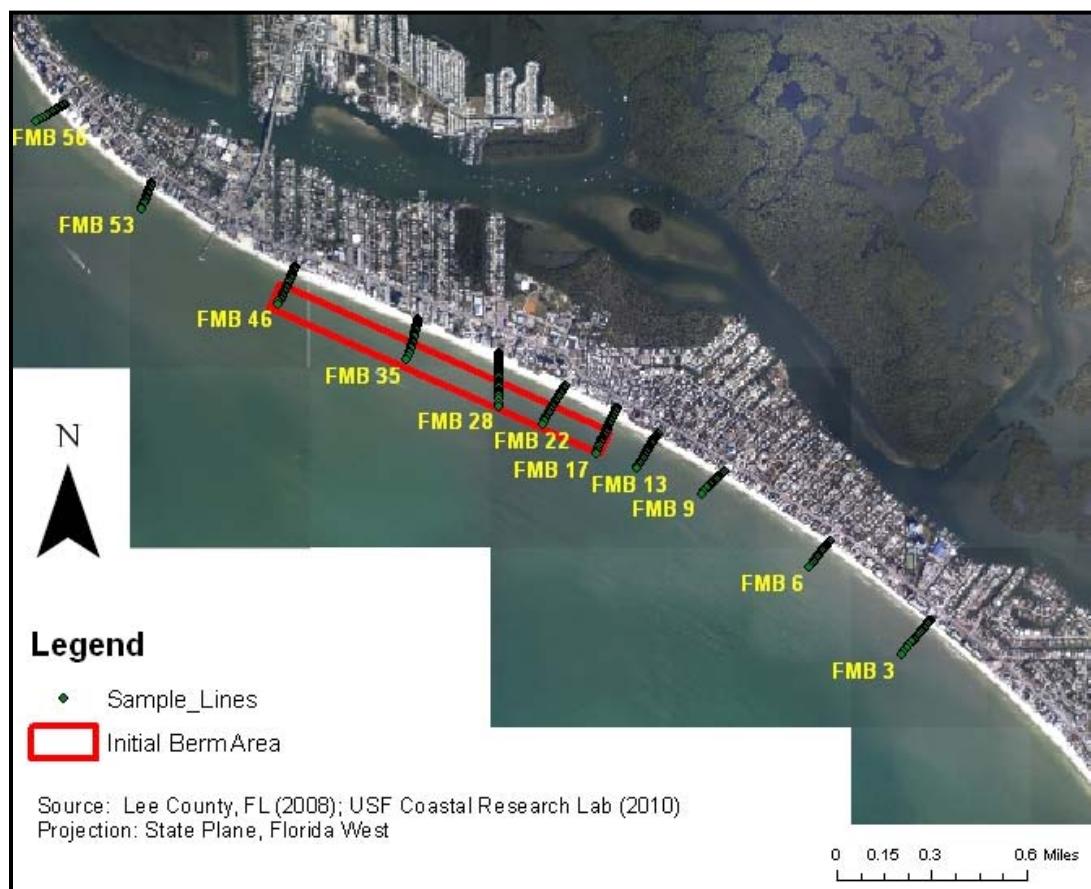


Figure D1. Locations of Sediment Sampling Transects.

Appendix D. (Continued)

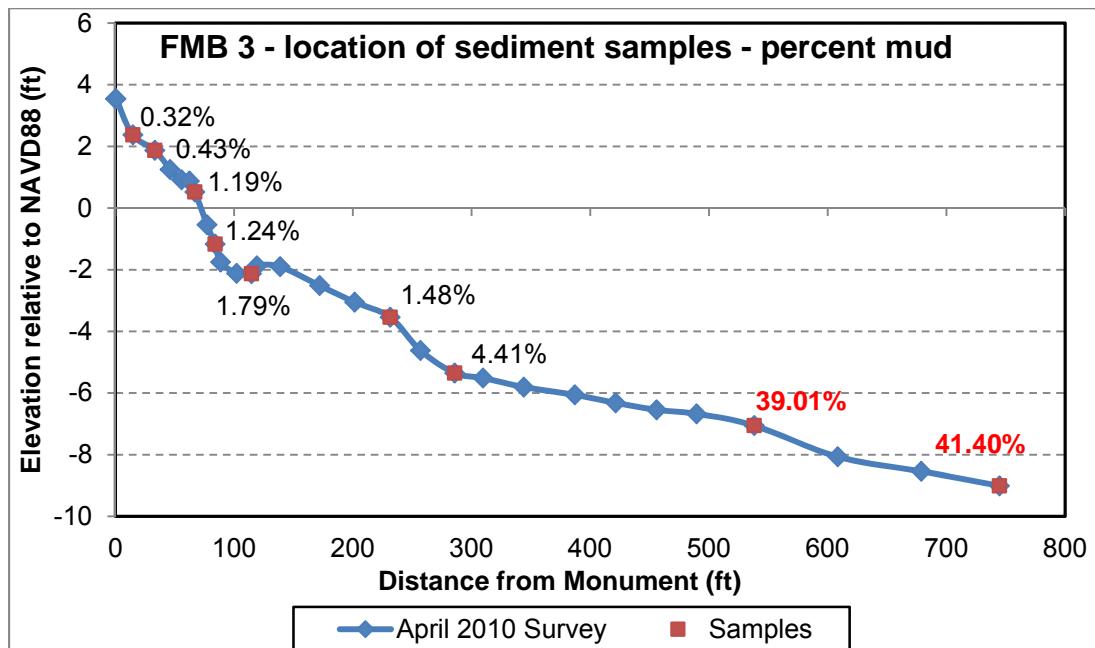


Figure D2. Sample Locations with Mud Percentages at FMB 3.

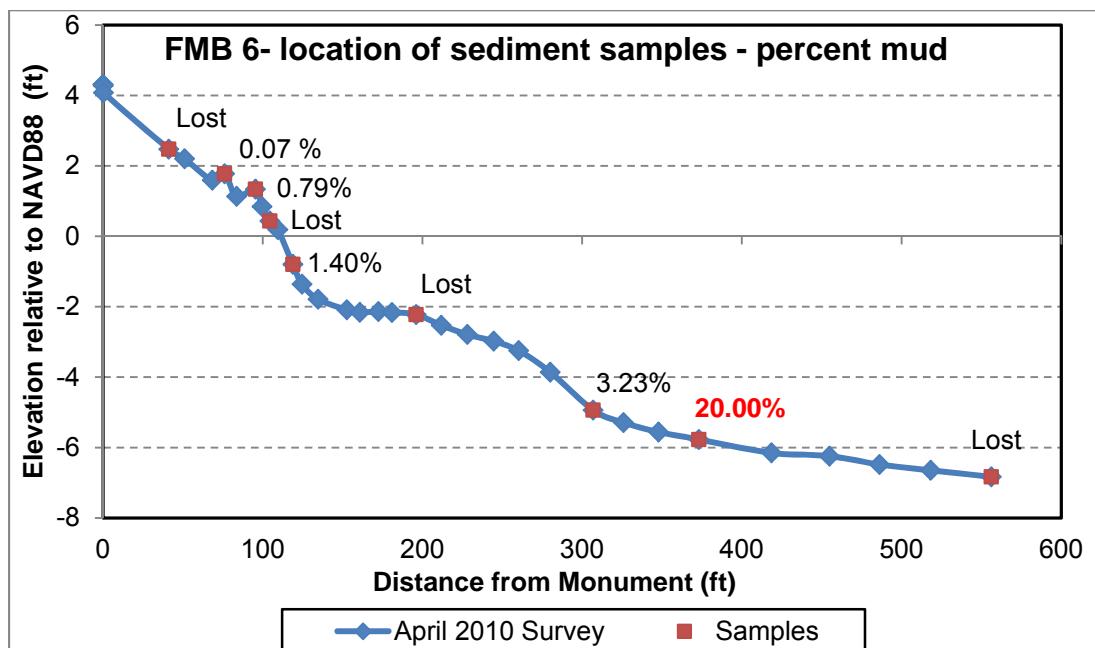


Figure D3. Sample Locations with Mud Percentages at FMB 6.

Appendix D. (Continued)

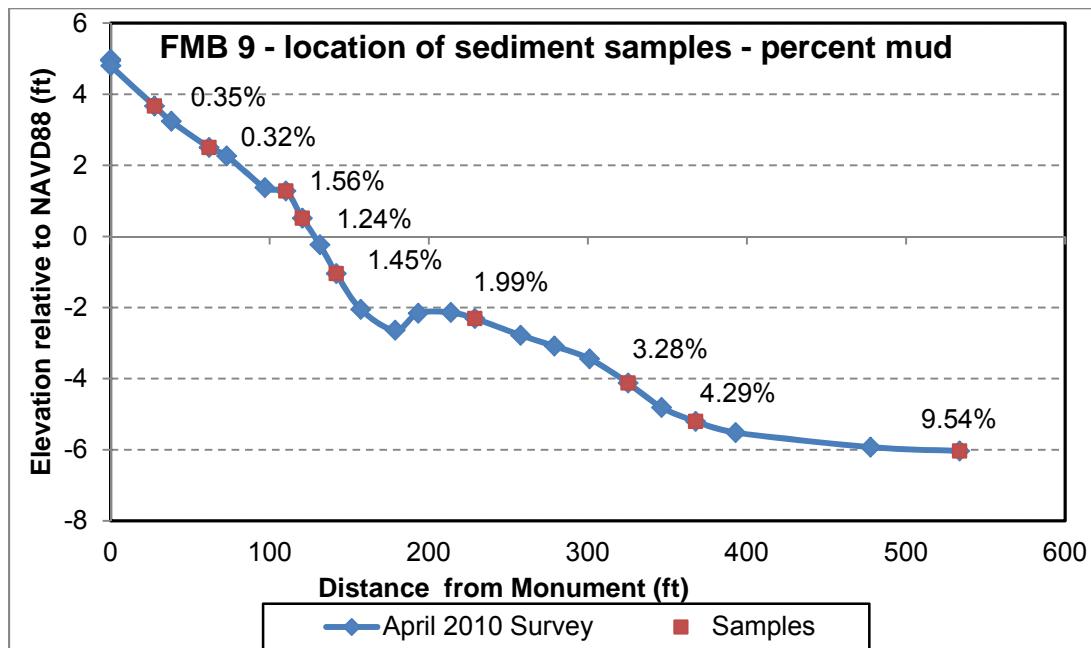


Figure D4. Sample Locations with Mud Percentages at FMB 9.

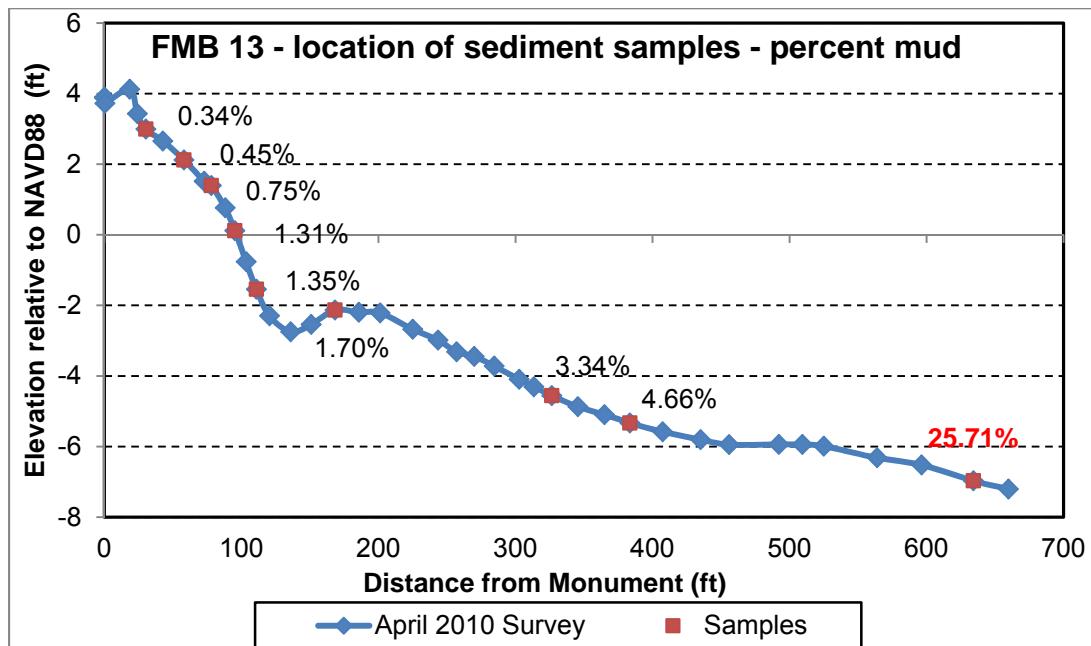


Figure D5. Sample Locations with Mud Percentages at FMB 13.

Appendix D. (Continued)

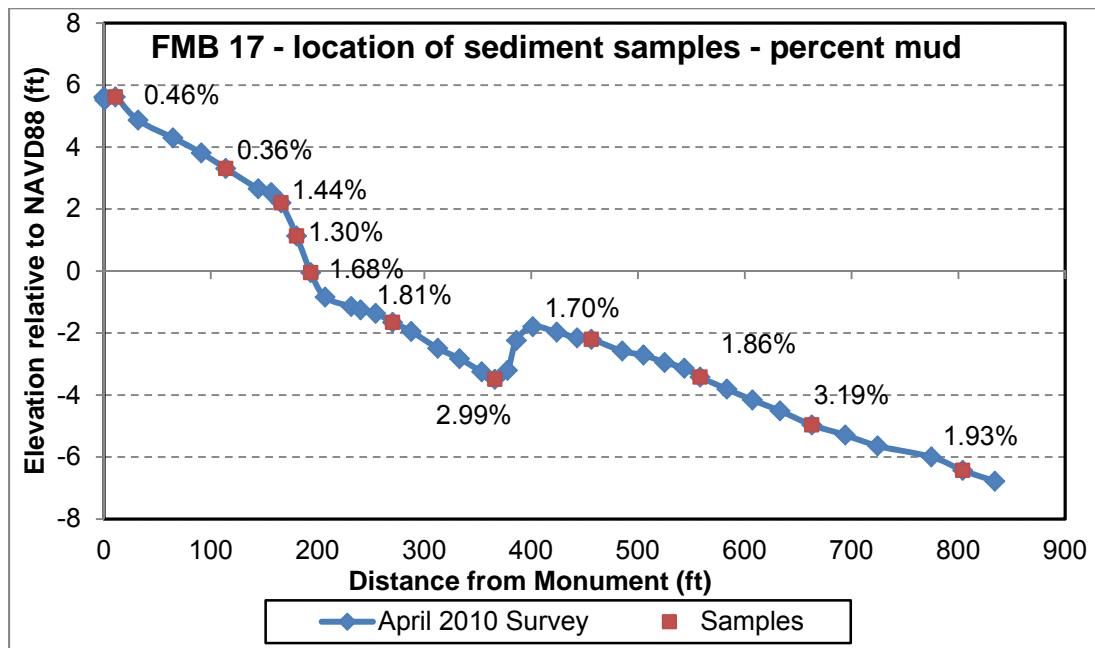


Figure D6. Sample Locations with Mud Percentages at FMB 17.

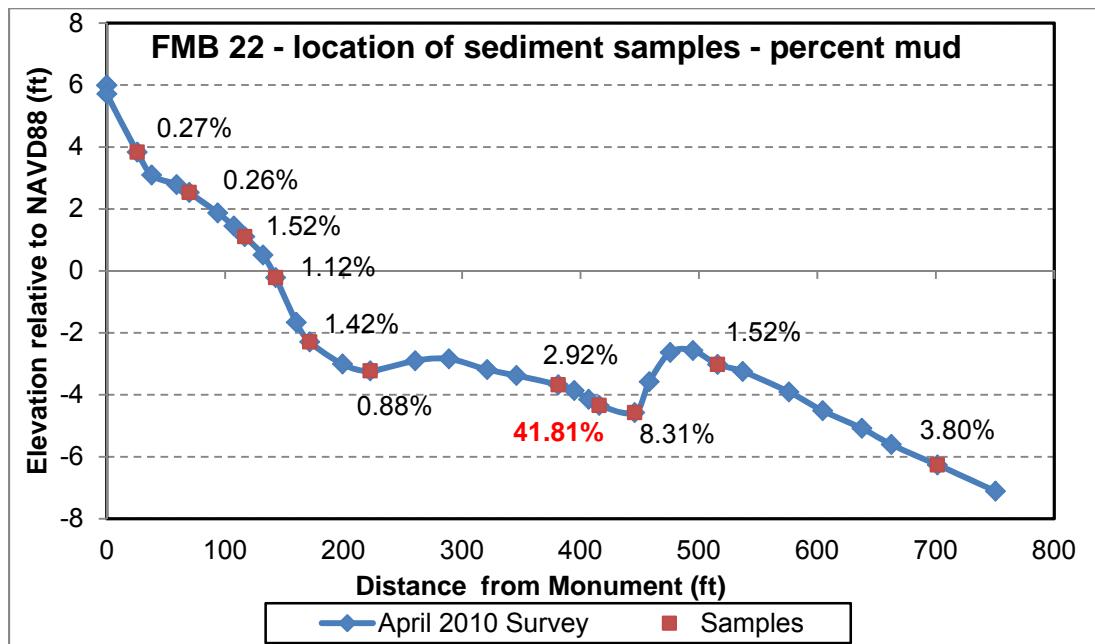


Figure D7. Sample Locations with Mud Percentages at FMB 22.

Appendix D. (Continued)

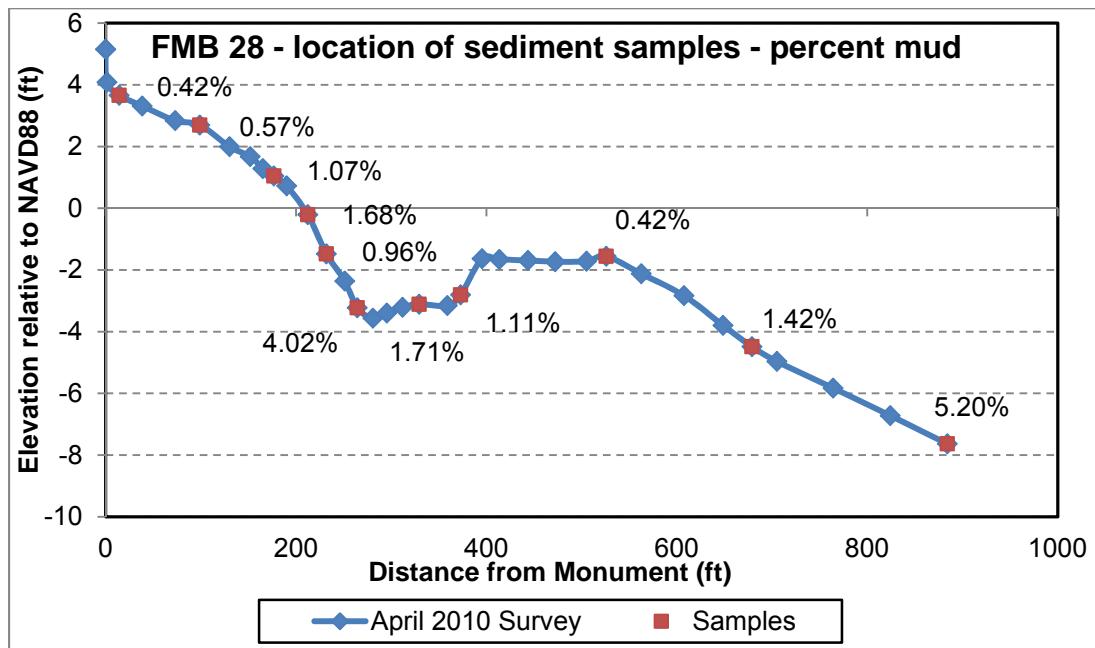


Figure D8. Sample Locations with Mud Percentages at FMB 28.

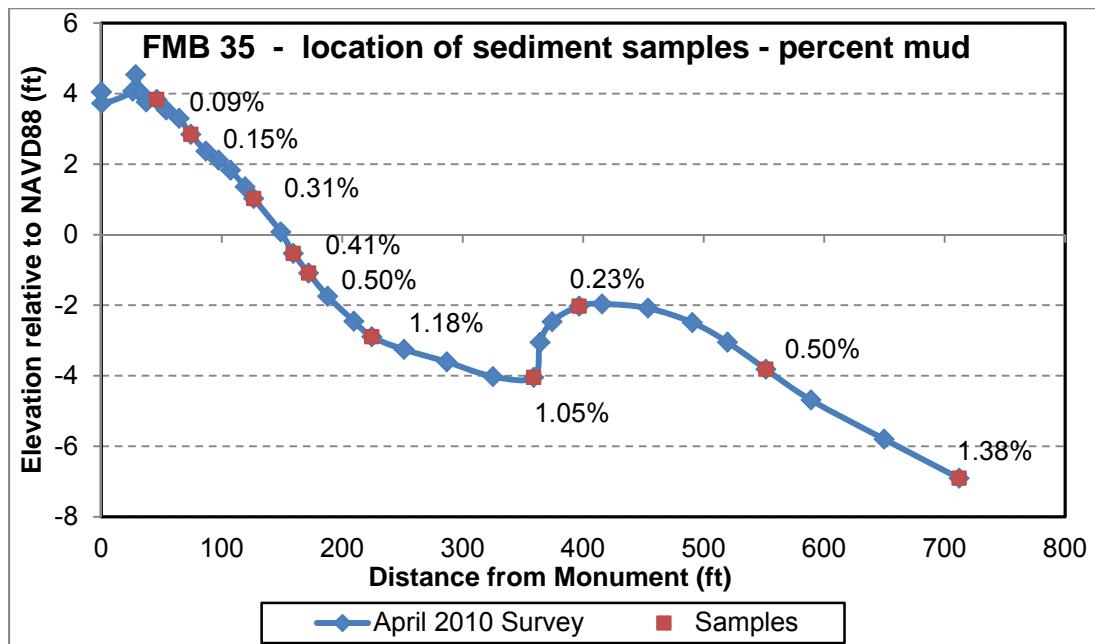


Figure D9. Sample Locations with Mud Percentages at FMB 35.

Appendix D. (Continued)

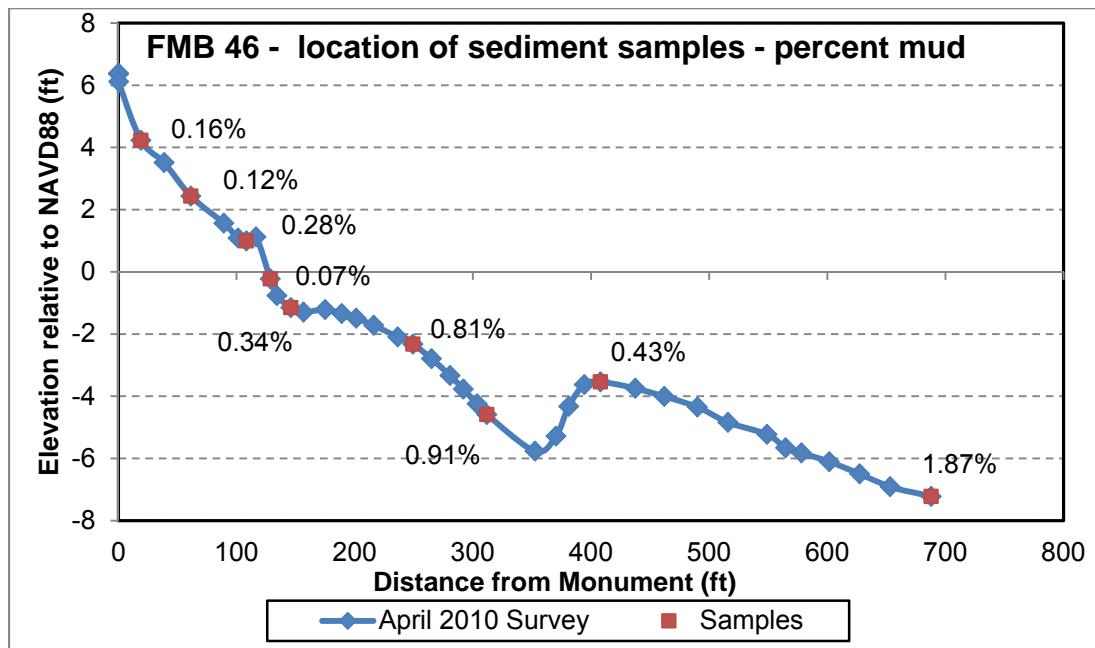


Figure D10. Sample Locations with Mud Percentages at FMB 46.

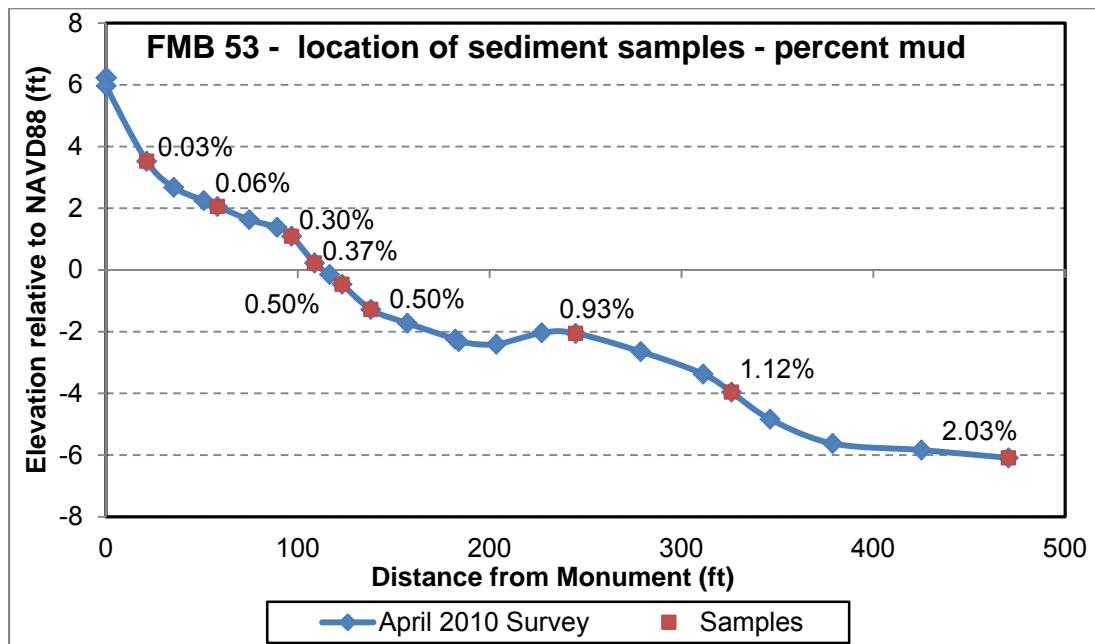


Figure D11. Sample Locations with Mud Percentages at FMB 53.

Appendix D. (Continued)

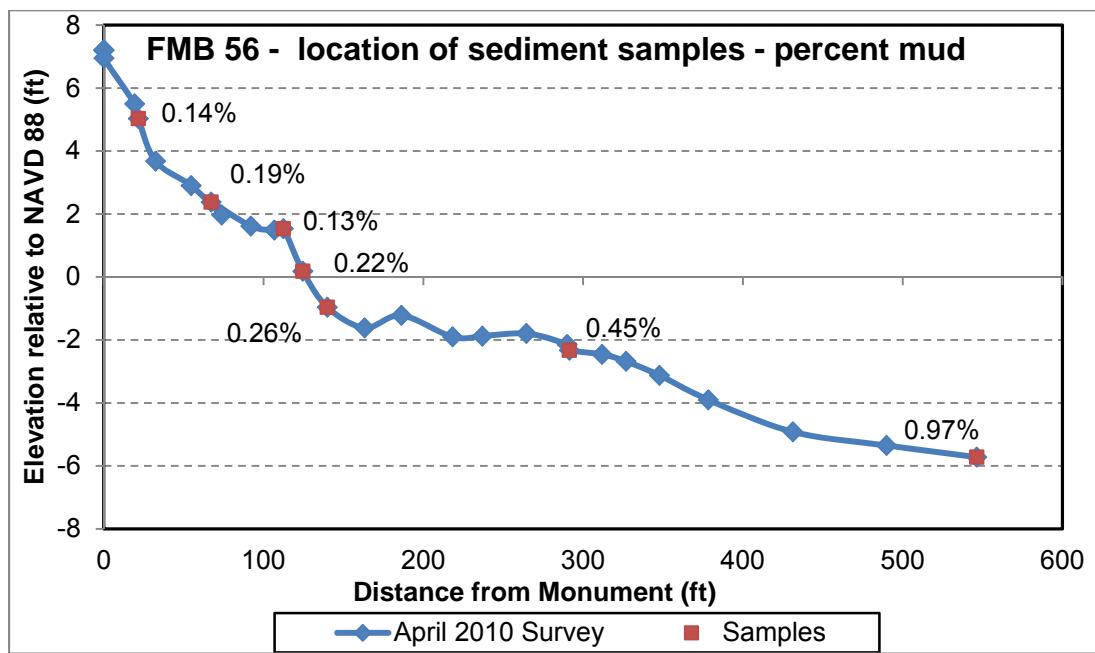


Figure D12. Sample Locations with Mud Percentages at FMB 56.

Appendix E. Sediment Sample Locations with CaCO₃ Percentages

The figures in Appendix E illustrate the beach profile of each of the sample lines, with the sample locations indicated by red squares. Percentages of carbonates in the samples are given next to each sample location. Figure E1 shows the sampling transect locations.

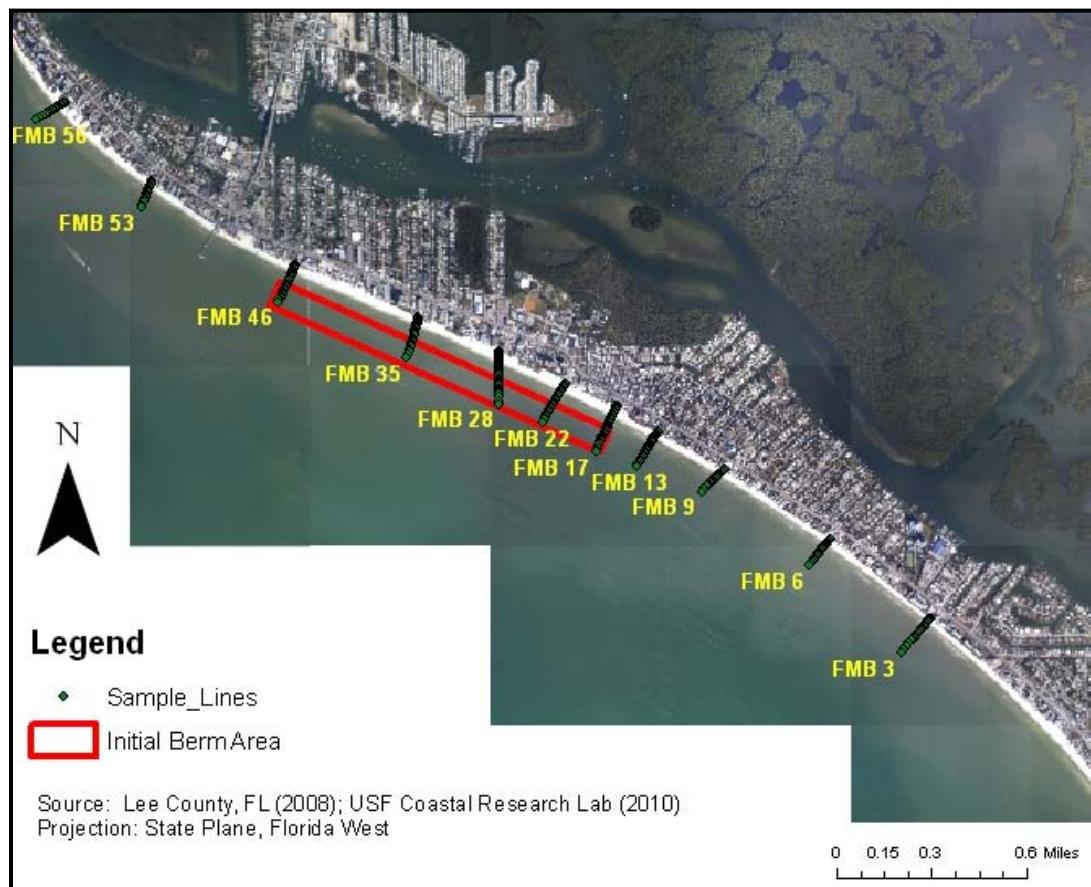


Figure E1. Locations of Sediment Sampling Transects.

Appendix E. (Continued)

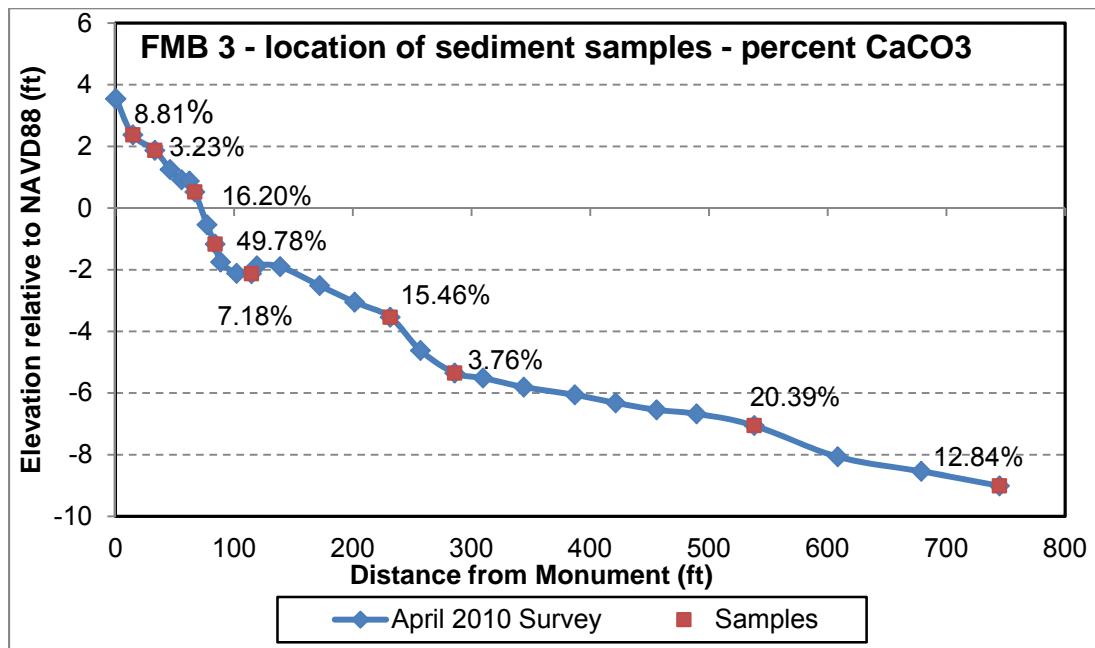


Figure E2. Sample Locations with CaCO₃ Percentages at FMB 3.

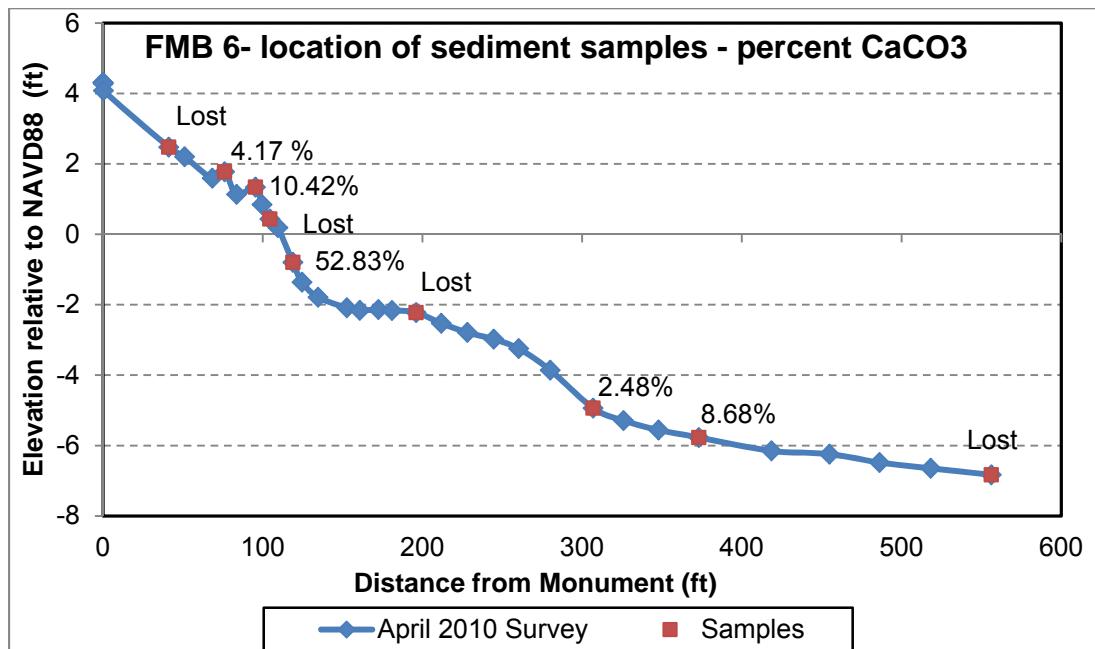


Figure E3. Sample Locations with CaCO₃ Percentages at FMB 6.

Appendix E. (Continued)

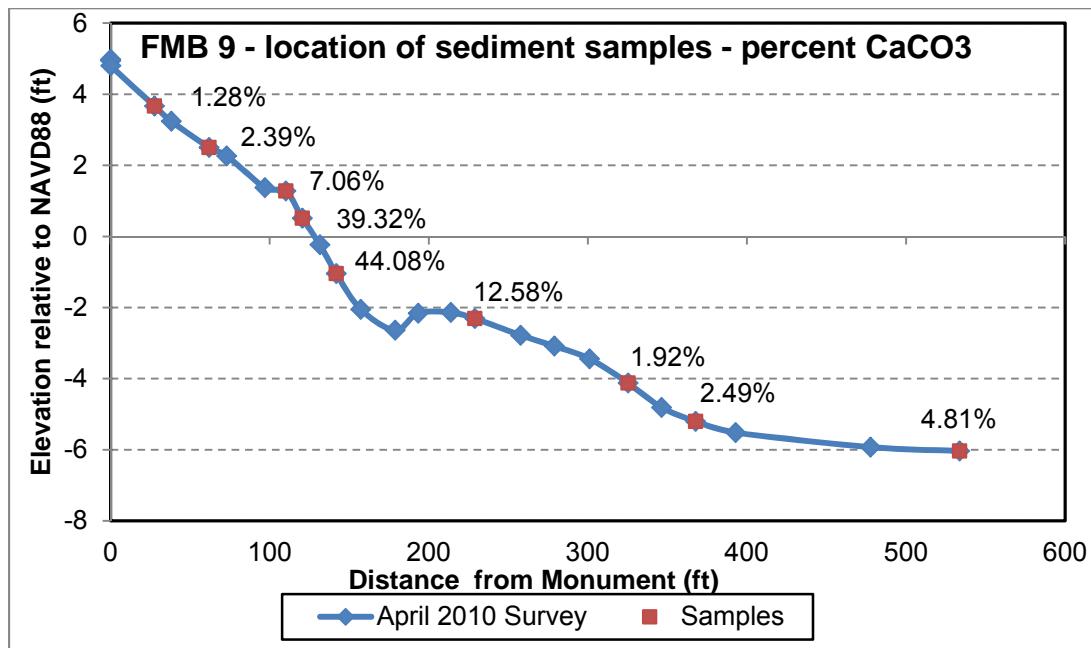


Figure E4. Sample Locations with CaCO₃ Percentages at FMB 9.

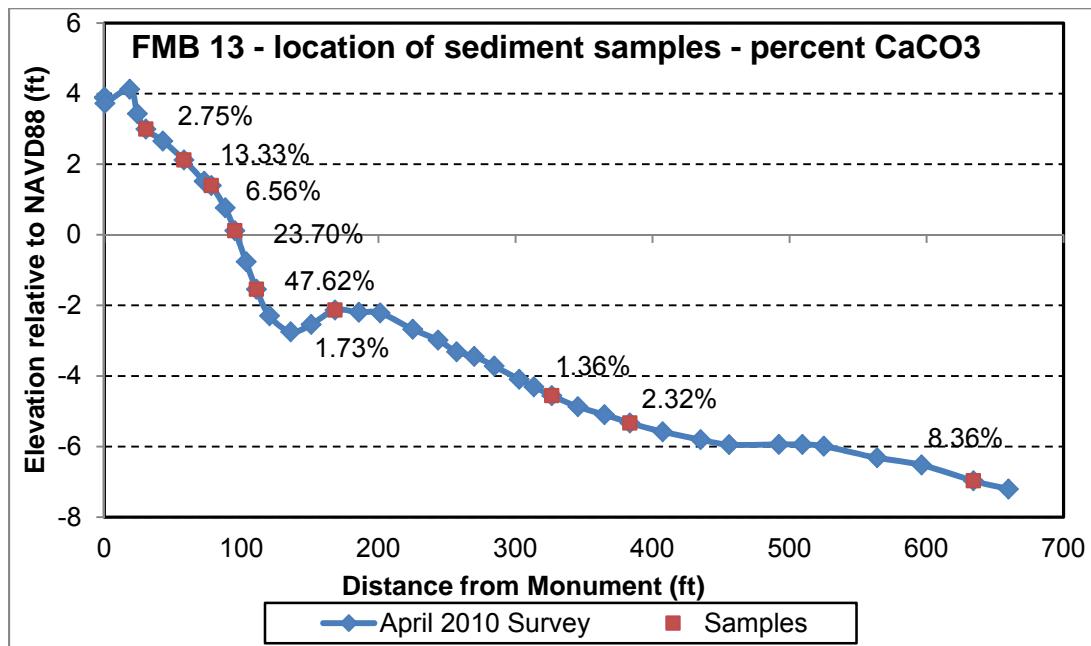


Figure E5. Sample Locations with CaCO₃ Percentages at FMB 13.

Appendix E. (Continued)

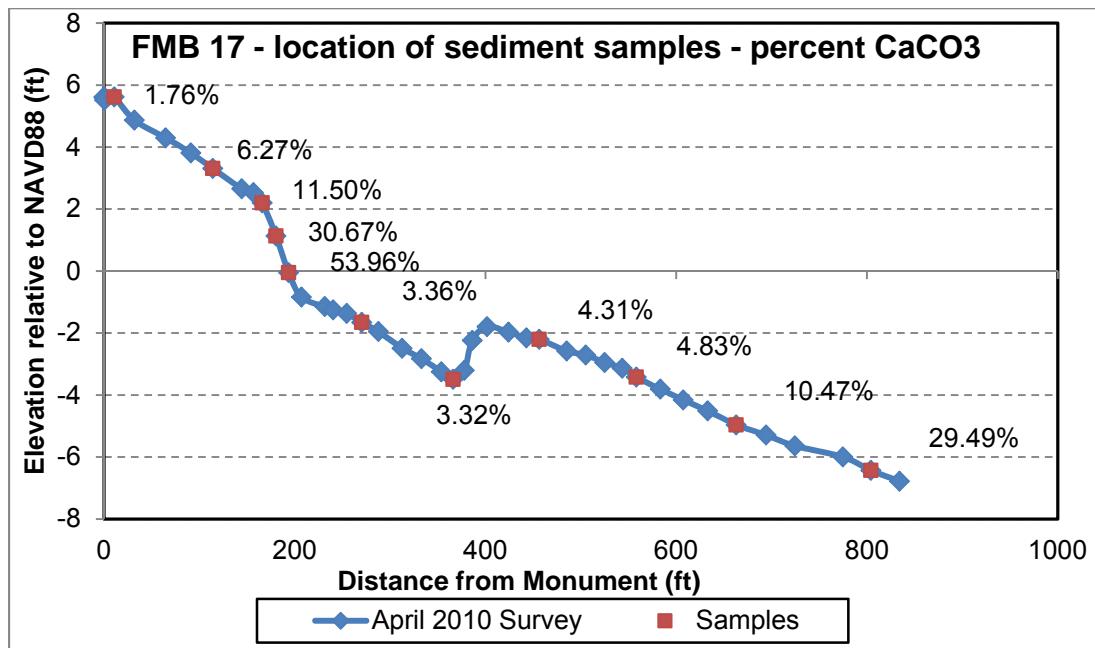


Figure E6. Sample Locations with CaCO₃ Percentages at FMB 17.

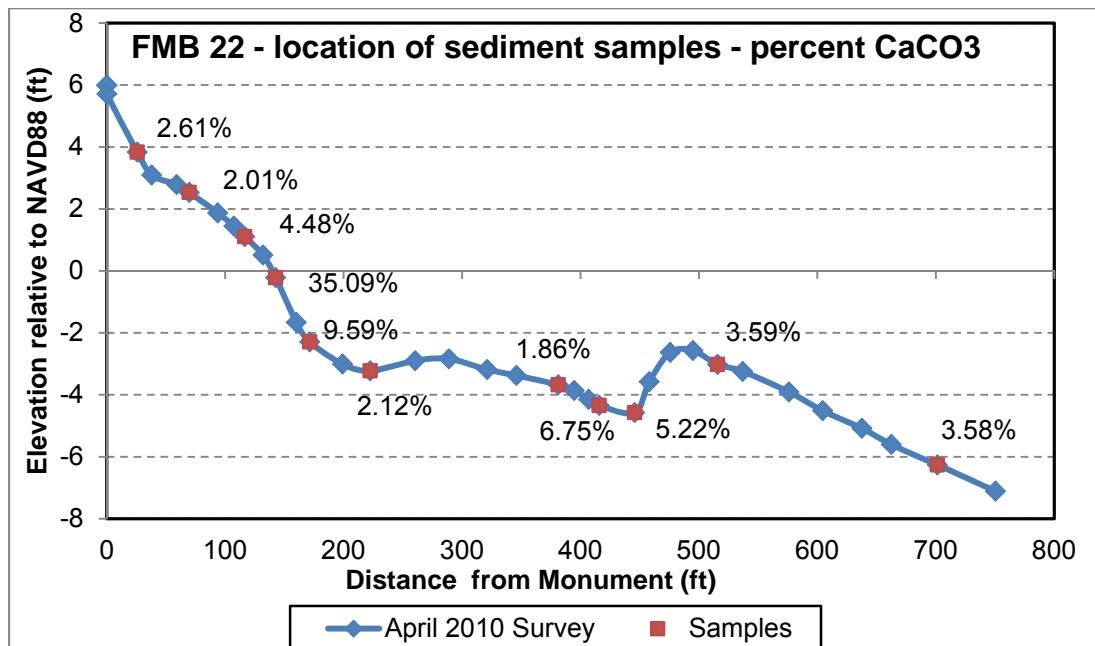


Figure E7. Sample Locations with CaCO₃ Percentages at FMB 22.

Appendix E. (Continued)

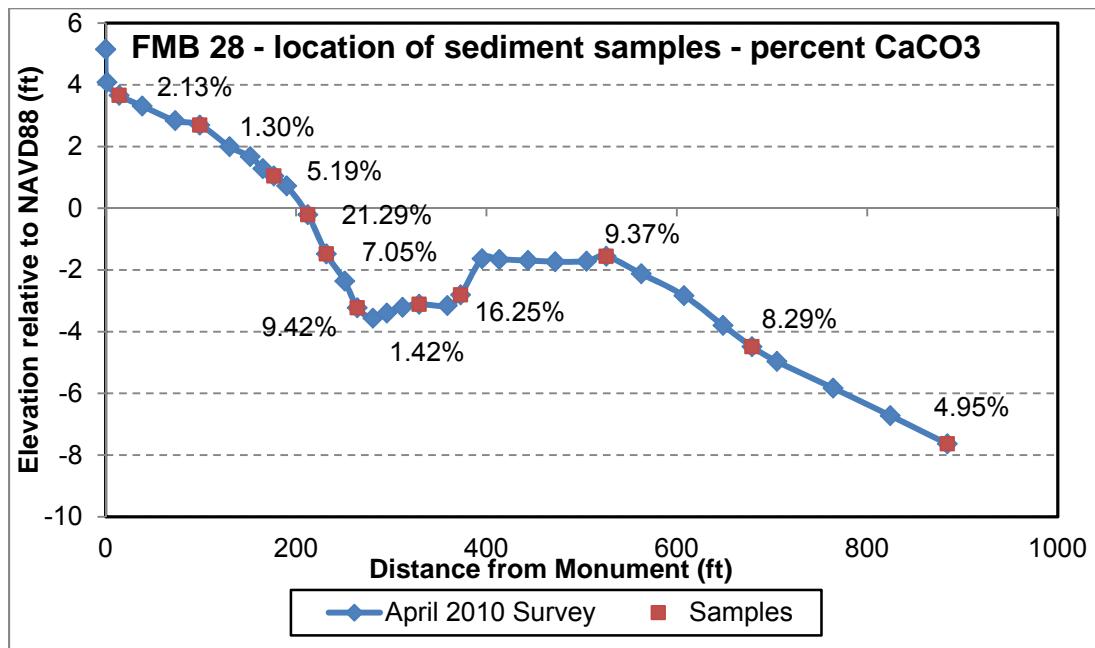


Figure E8. Sample Locations with CaCO₃ Percentages at FMB 28.

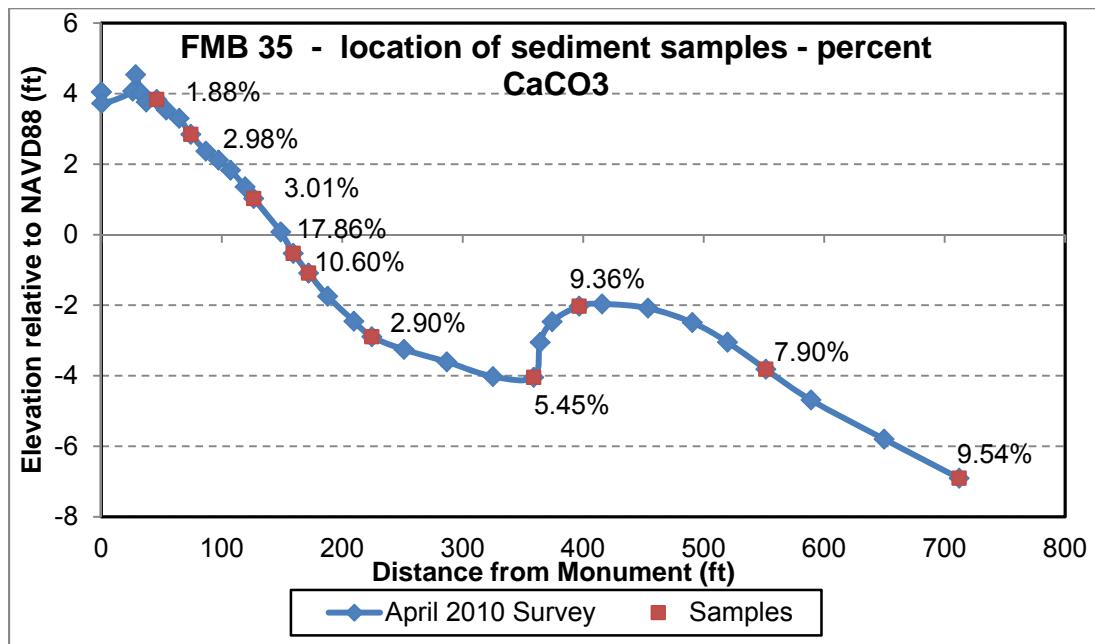


Figure E9. Sample Locations with CaCO₃ Percentages at FMB 35.

Appendix E. (Continued)

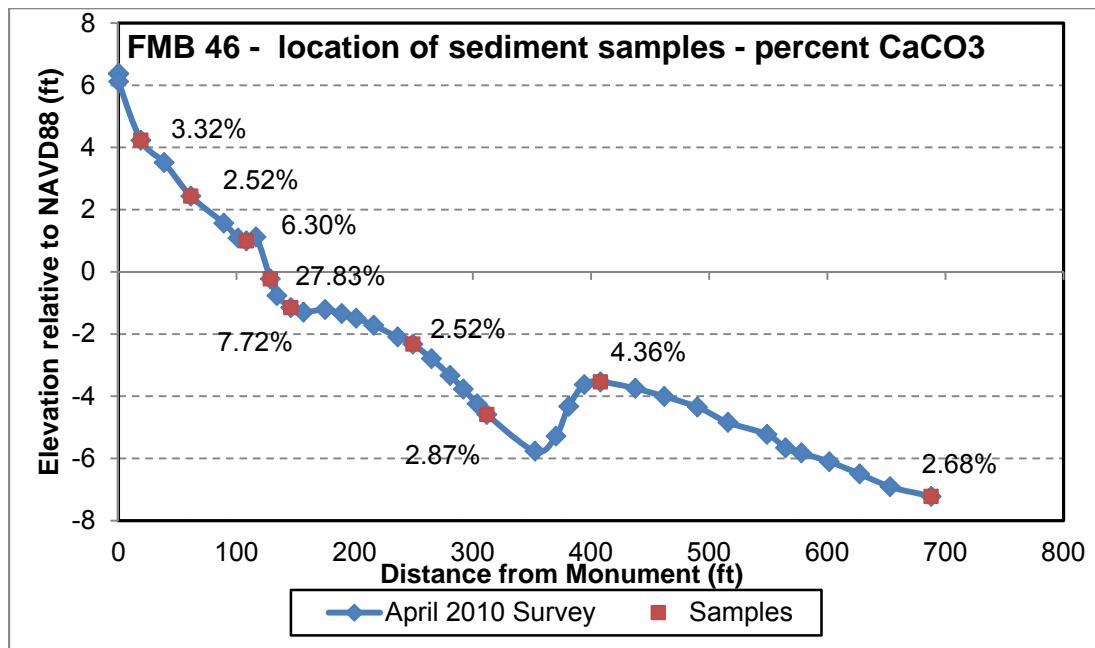


Figure E10. Sample Locations with CaCO₃ Percentages at FMB 46.

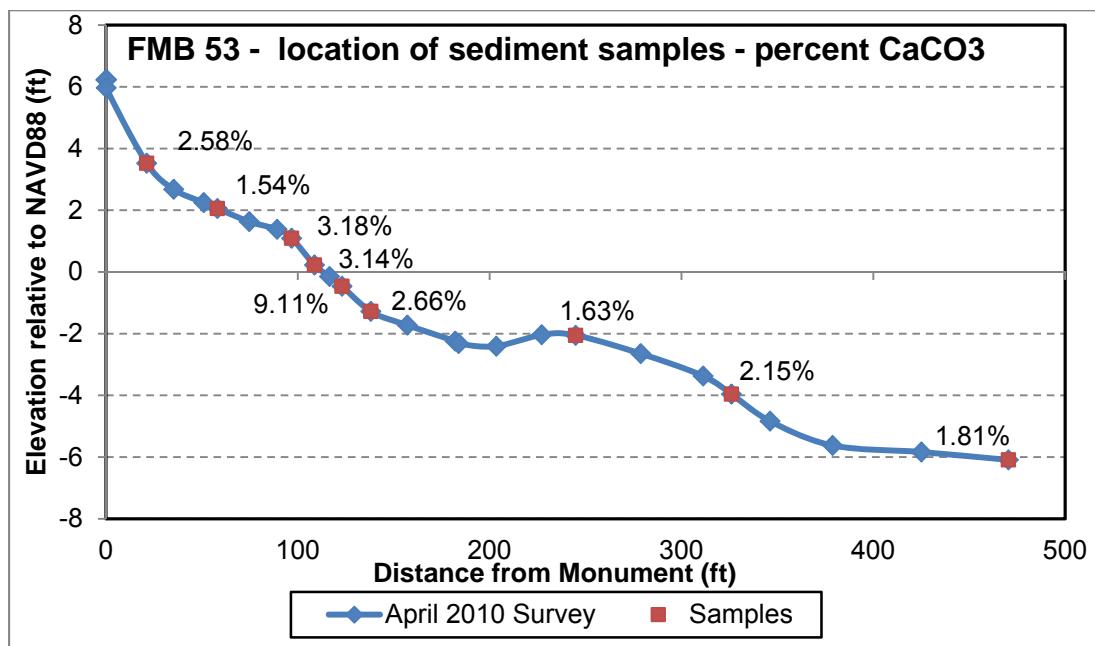


Figure E11. Sample Locations with CaCO₃ Percentages at FMB 53.

Appendix E. (Continued)

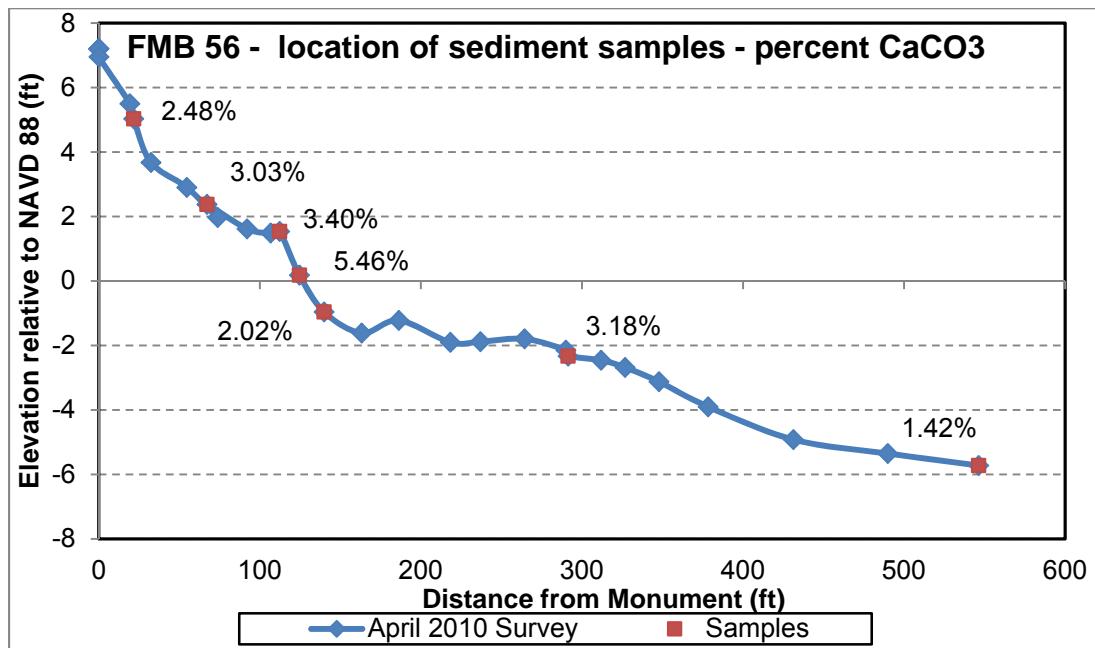


Figure E12. Sample Locations with CaCO_3 Percentages at FMB 56.

Appendix F. USACE Survey Data

The following appendix includes beach profiles created from survey data recorded by USACE pre- and post- construction of the berm (May 2009 and October 2009, respectively). Figure F1 is a map showing the location of each beach profile. All elevations are relative to NAVD88, and all distances are relative to a monument.

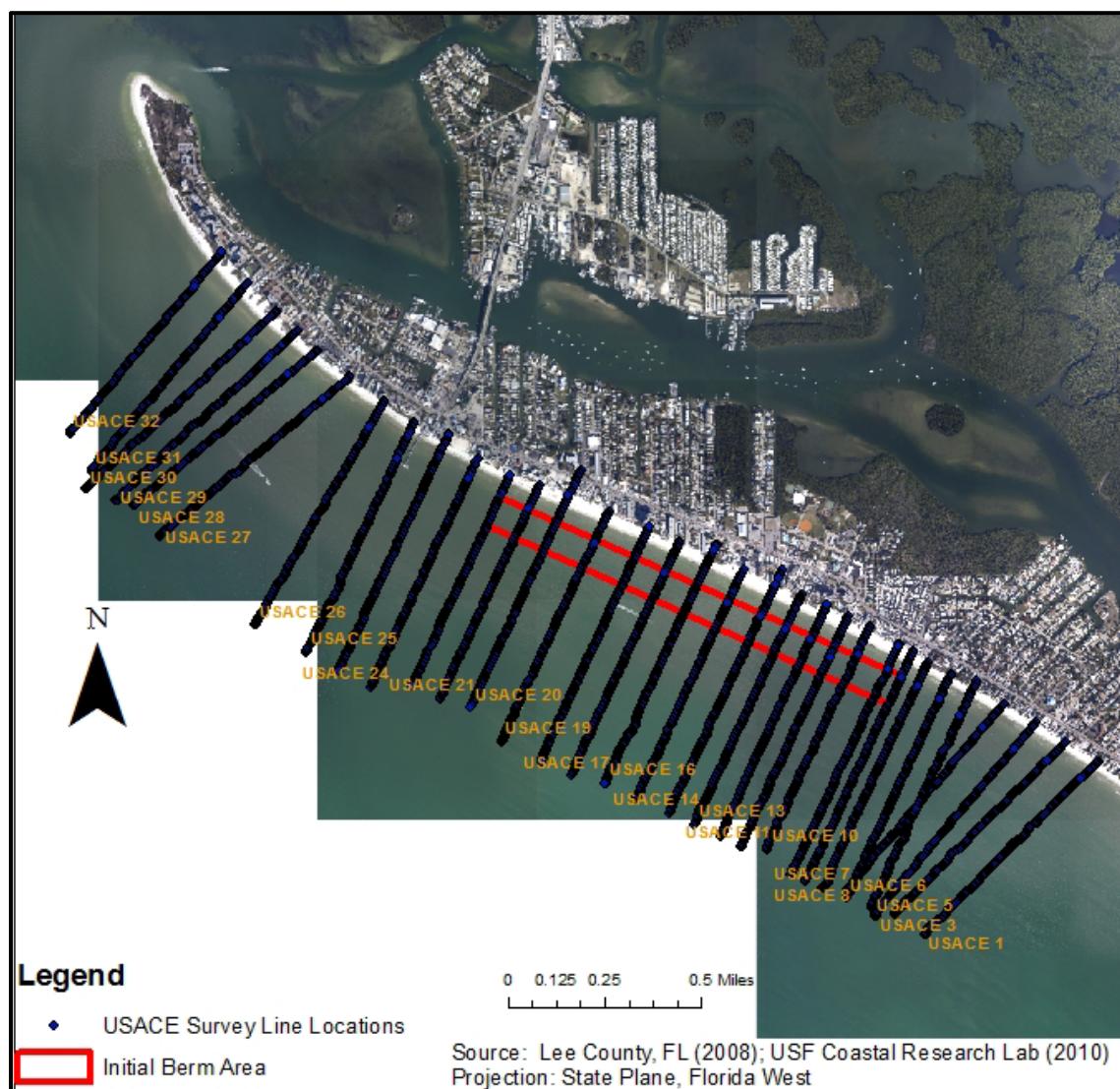


Figure F1. USACE Survey Line Locations.

Appendix F. (Continued)

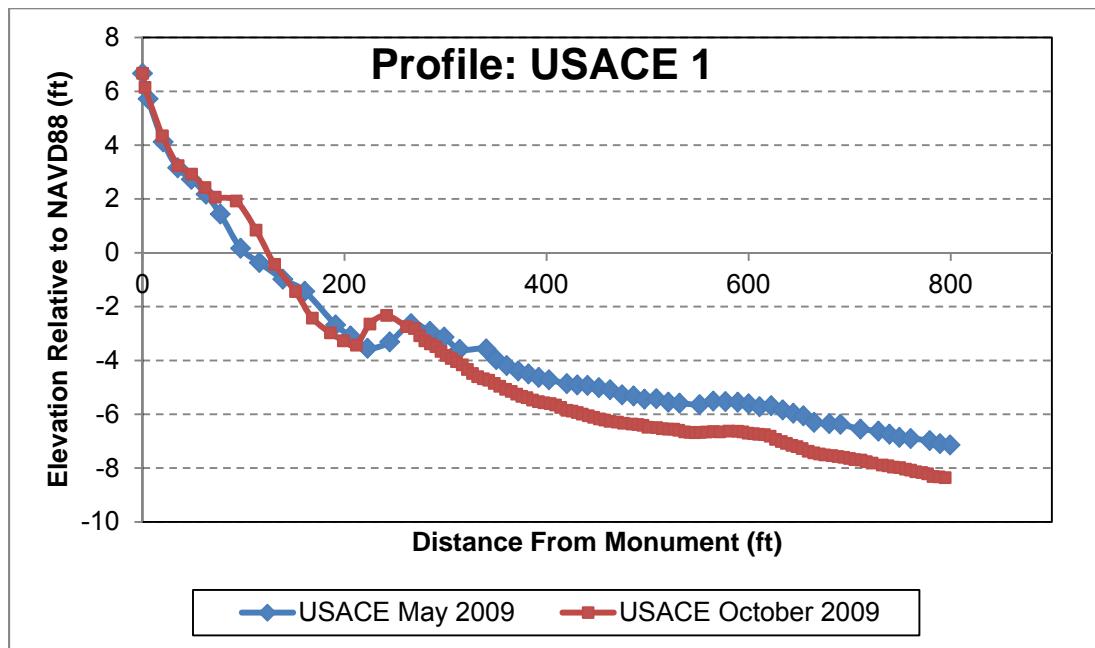


Figure F2. Beach Profile at USACE 1.

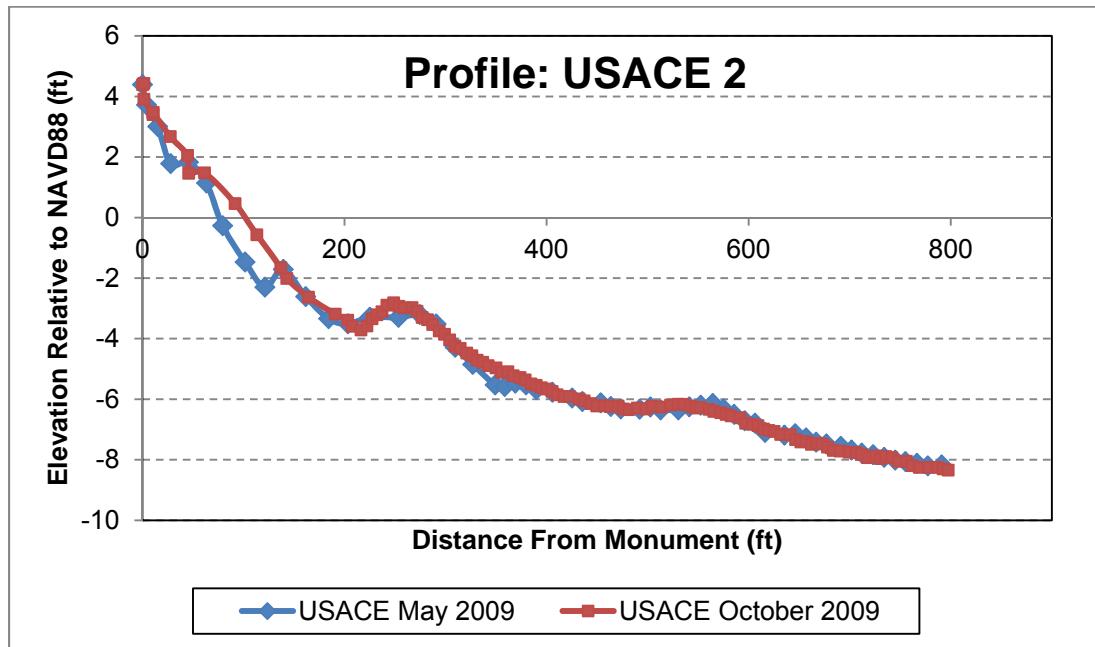


Figure F3. Beach Profile at USACE 2.

Appendix F. (Continued)

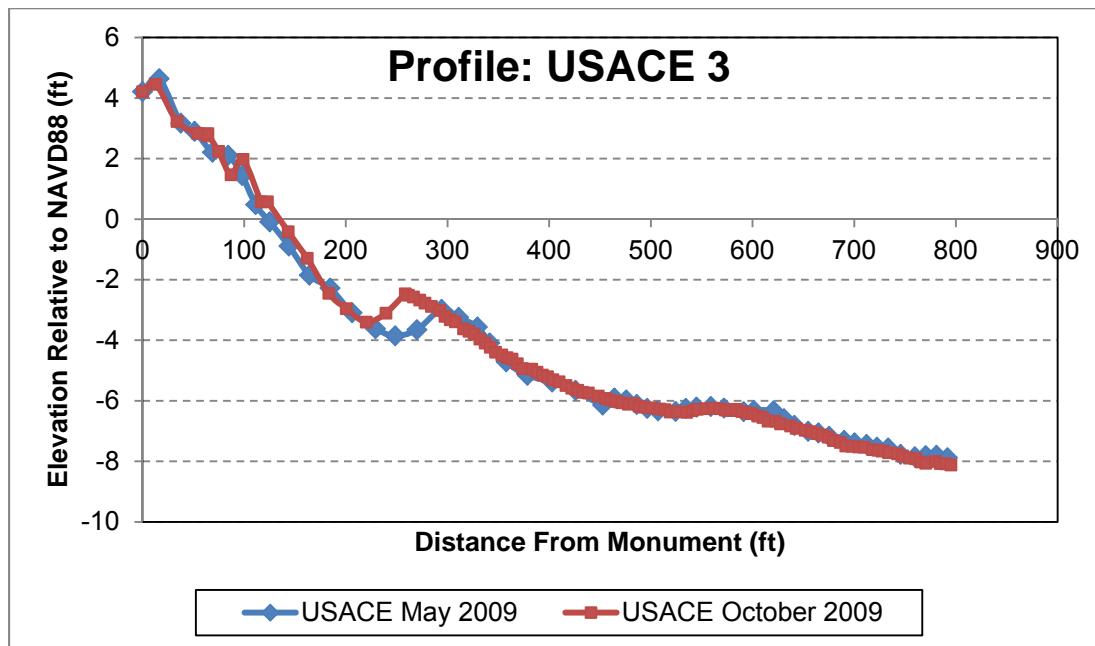


Figure F4. Beach Profile at USACE 3.

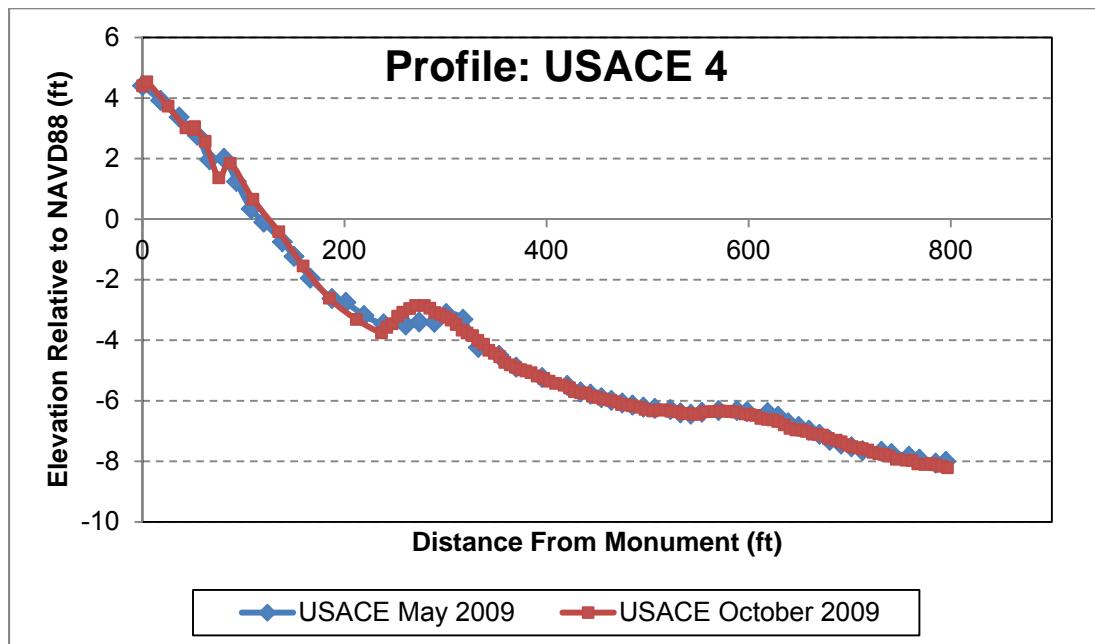


Figure F5. Beach Profile at USACE 4.

Appendix F. (Continued)

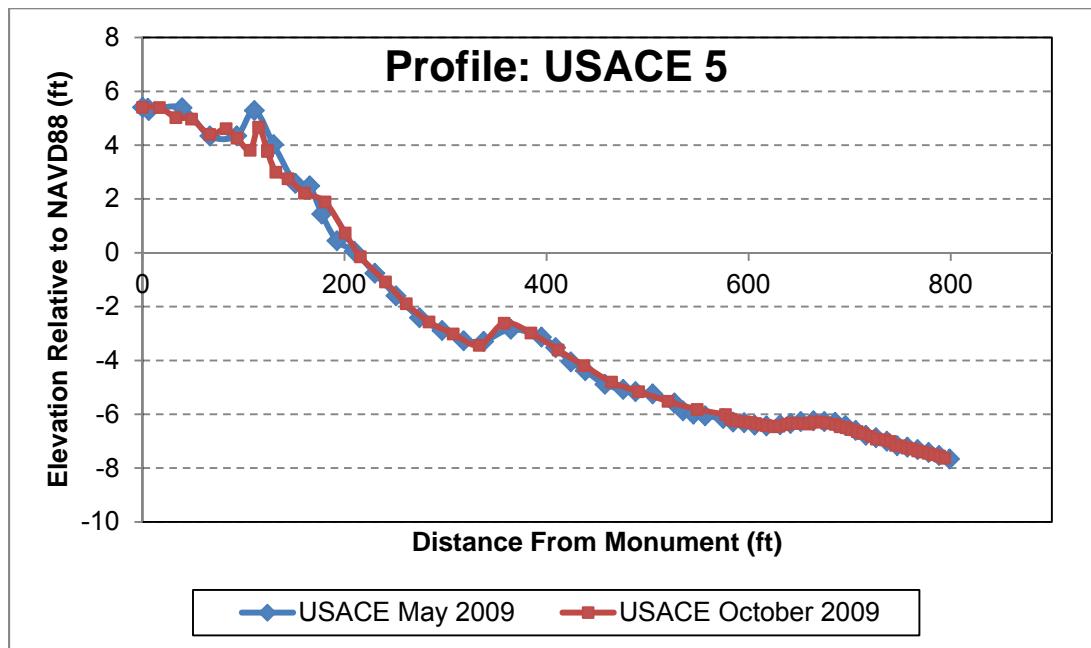


Figure F6. Beach Profile at USACE 5.

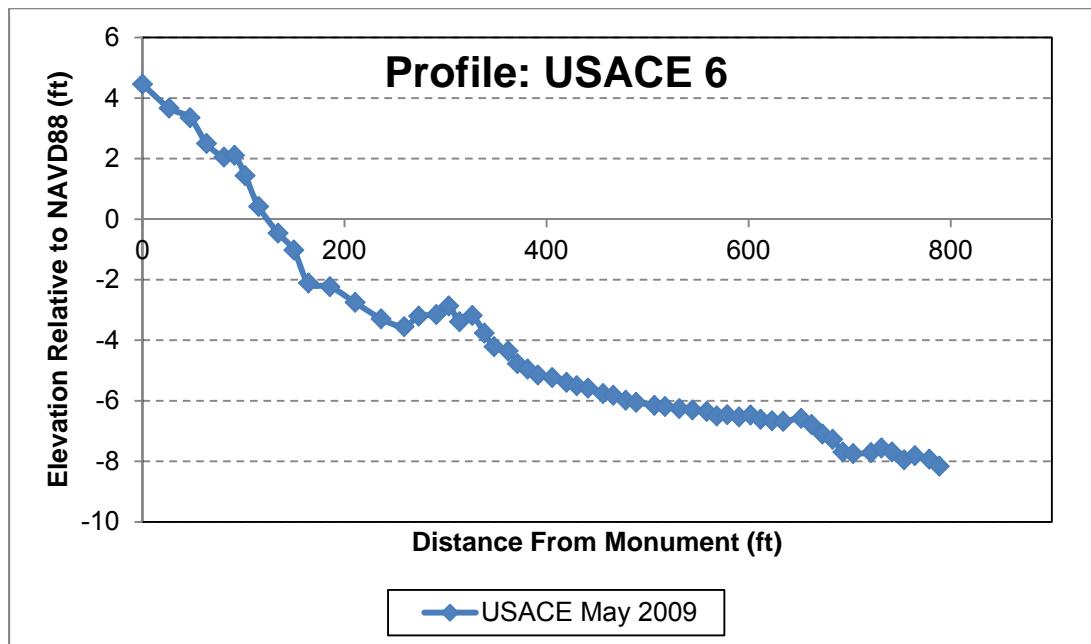


Figure F7. Beach Profile at USACE 6.

Appendix F. (Continued)

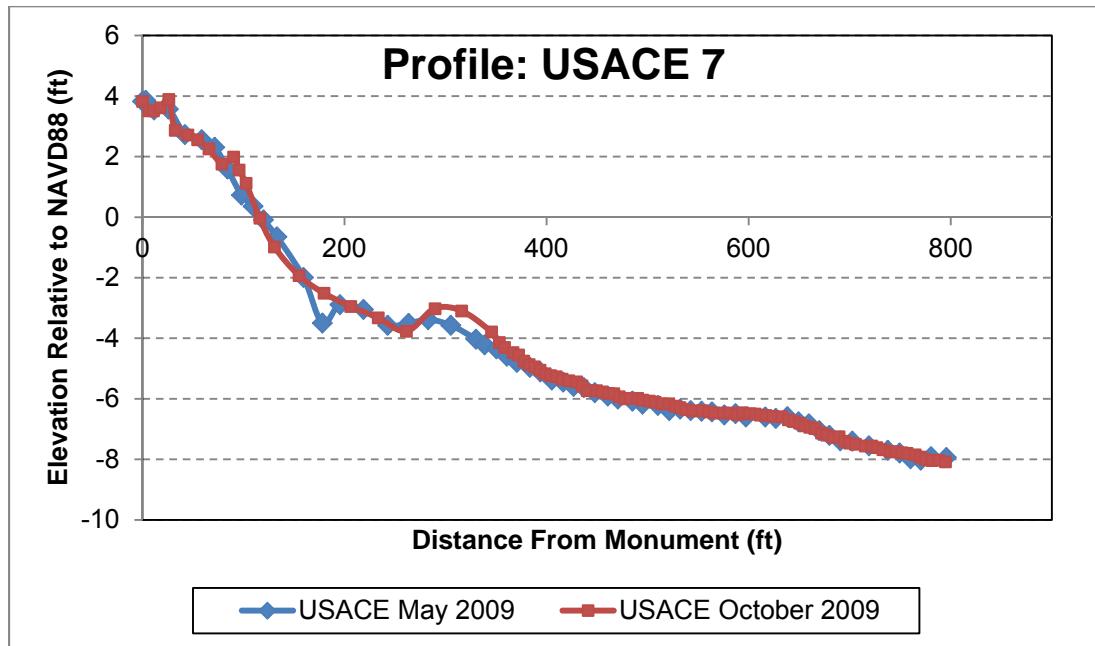


Figure F8. Beach Profile at USACE 7.

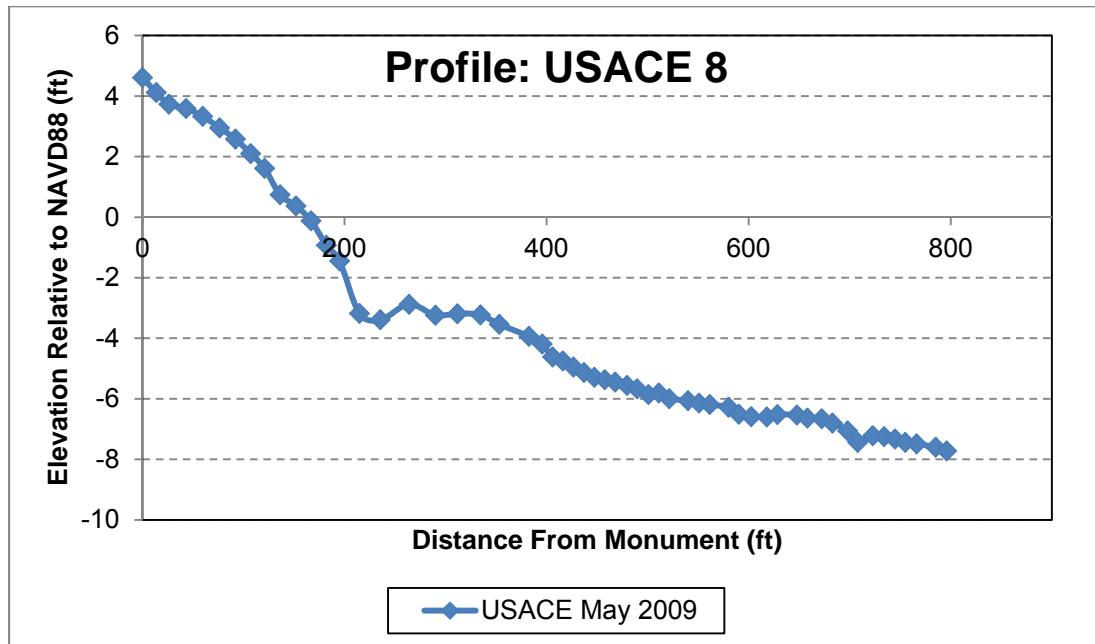


Figure F9. Beach Profile at USACE 8.

Appendix F. (Continued)

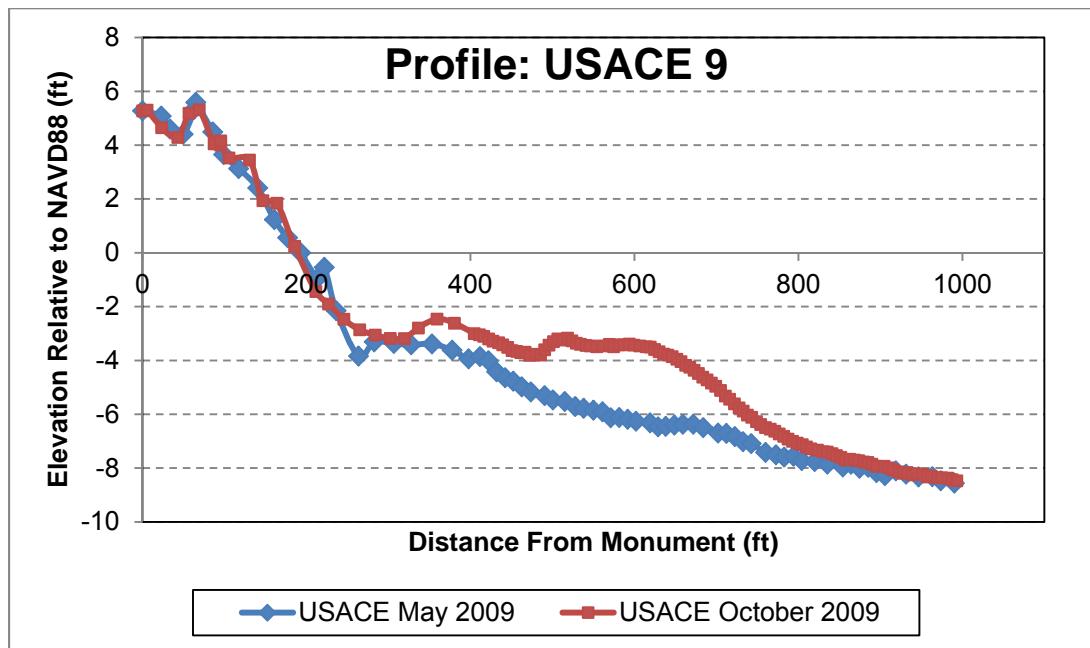


Figure F10. Beach Profile at USACE 9.

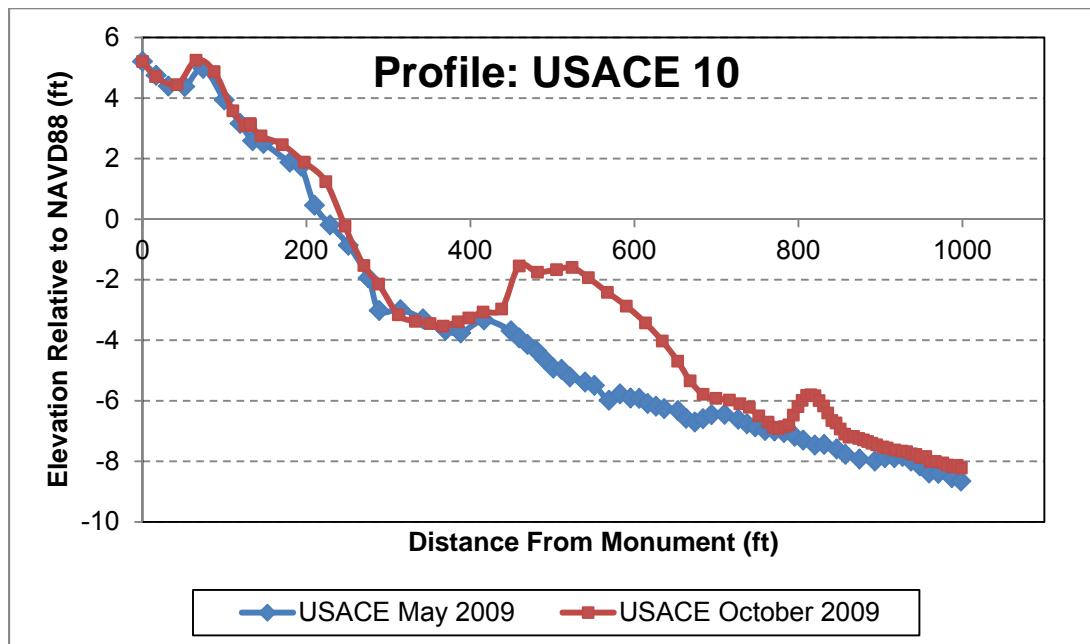


Figure F11. Beach Profile at USACE 10.

Appendix F. (Continued)

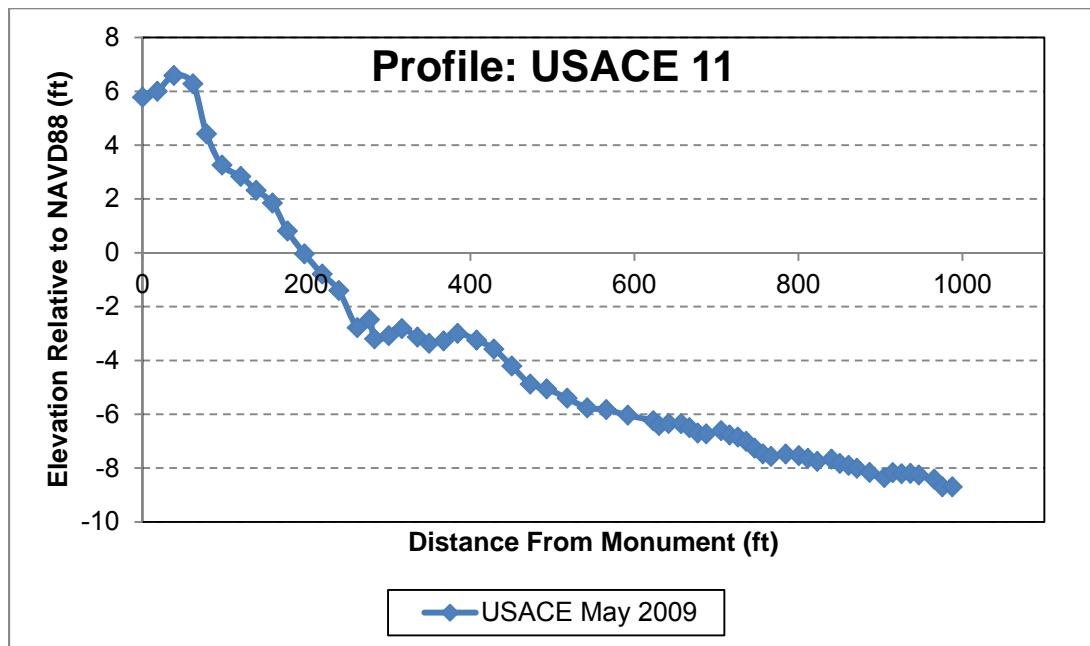


Figure F12. Beach Profile at USACE 11.

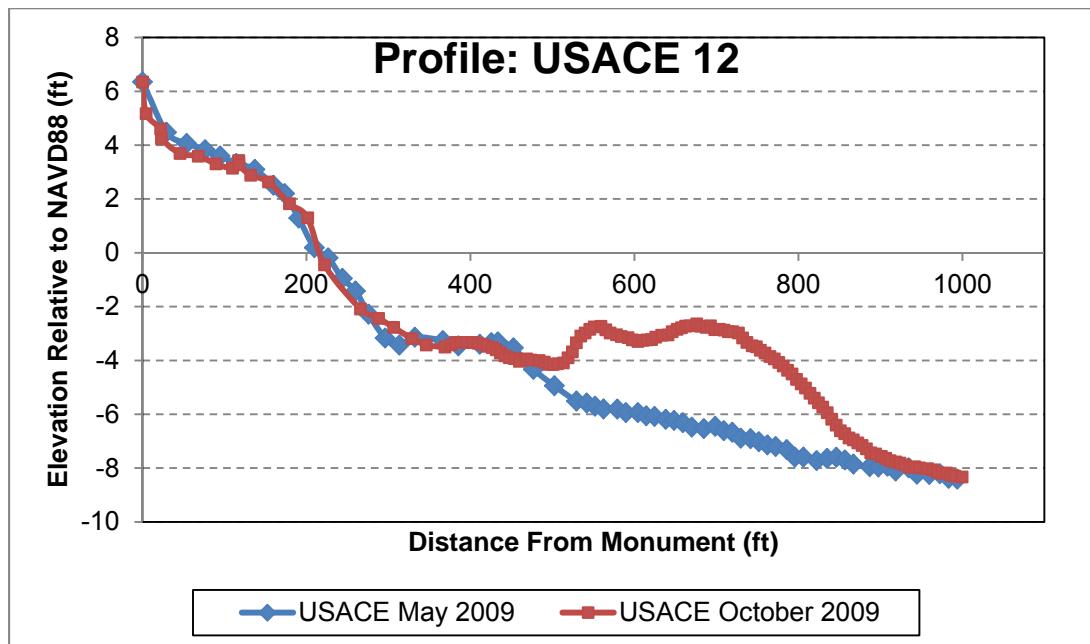


Figure F13. Beach Profile at USACE 12.

Appendix F. (Continued)

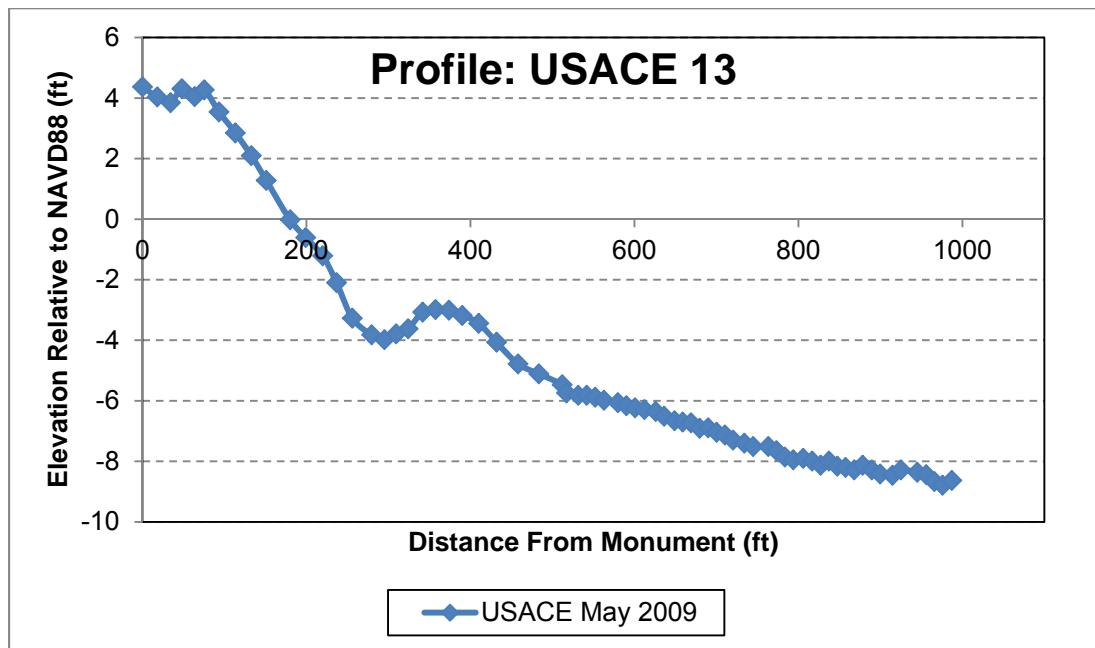


Figure F14. Beach Profile at USACE 13.

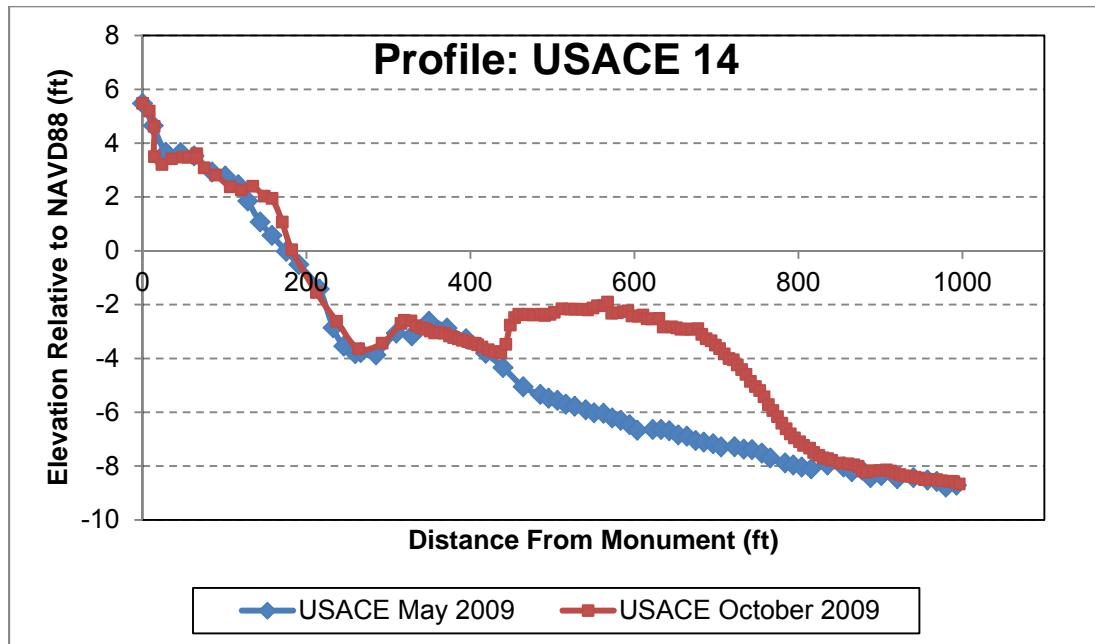


Figure F15. Beach Profile at USACE 14.

Appendix F. (Continued)

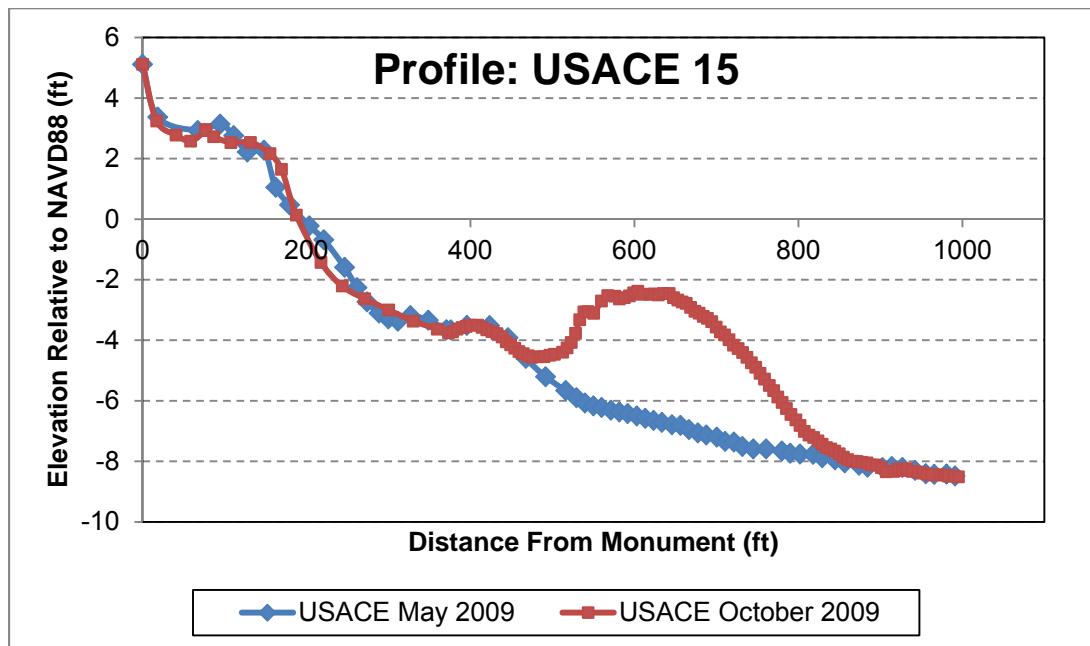


Figure F16. Beach Profile at USACE 15.

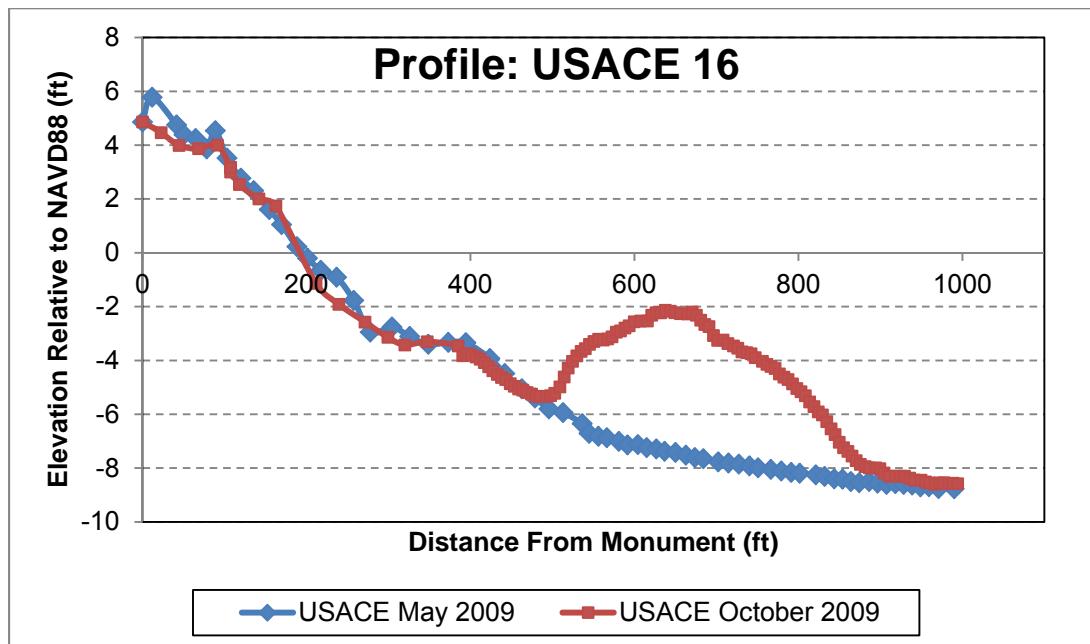


Figure F17. Beach Profile at USACE 16.

Appendix F. (Continued)

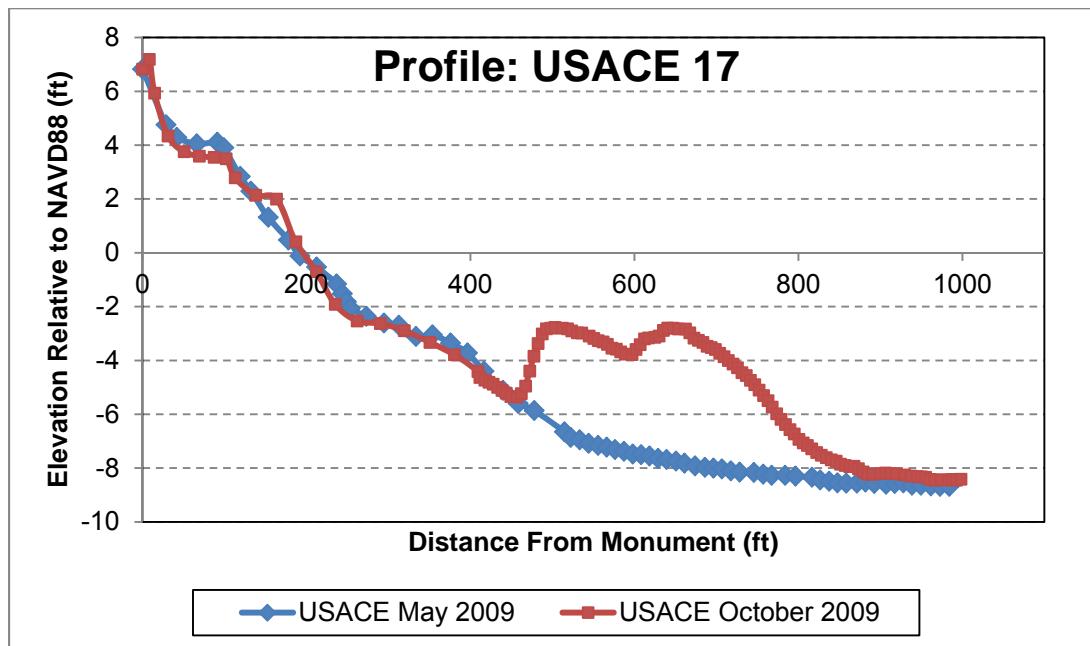


Figure F18. Beach Profile at USACE 17.

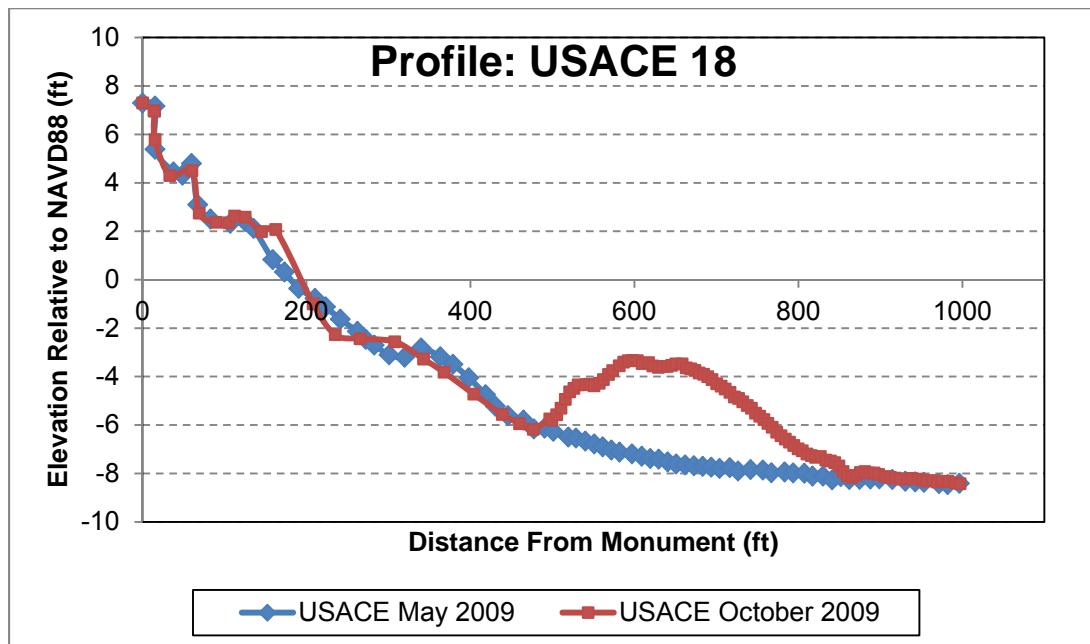


Figure F19. Beach Profile at USACE 18.

Appendix F. (Continued)

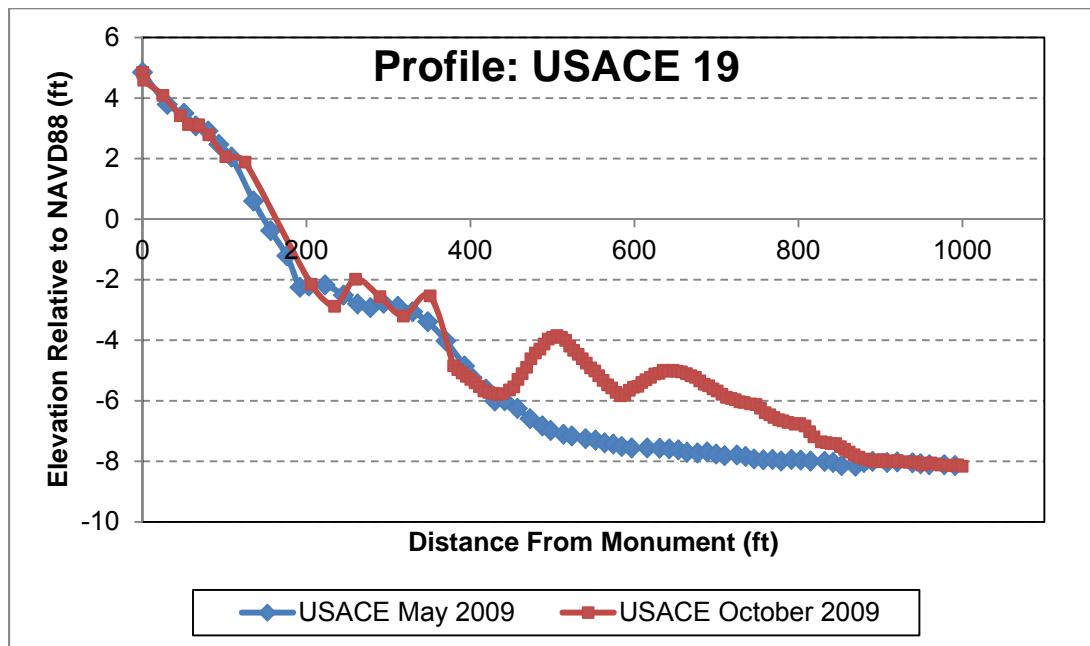


Figure F20. Beach Profile at USACE 19.

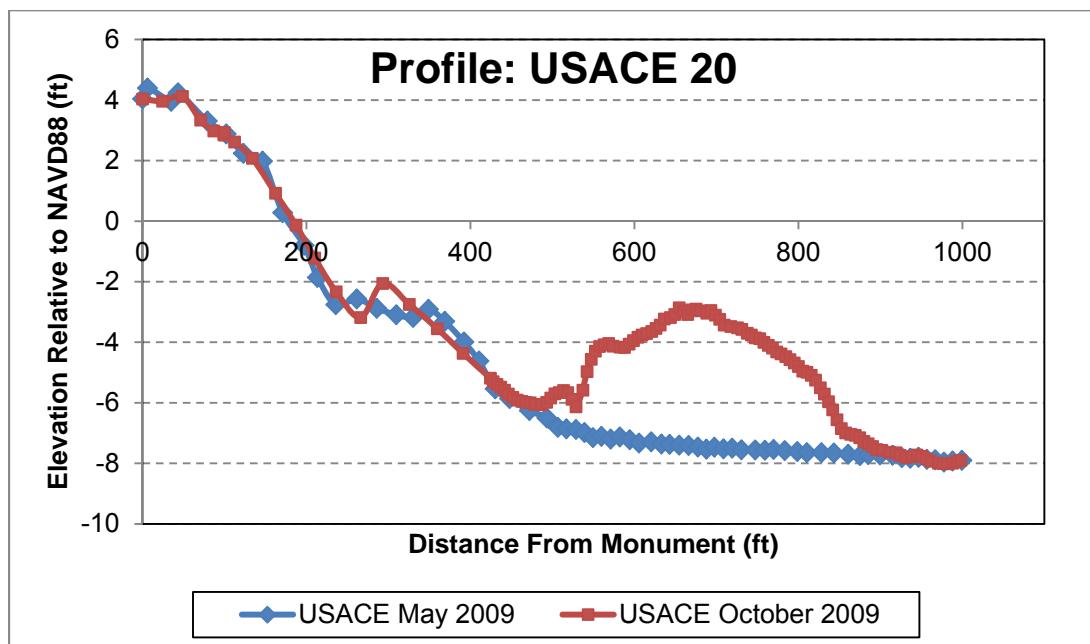


Figure F21. Beach Profile at USACE 20.

Appendix F. (Continued)

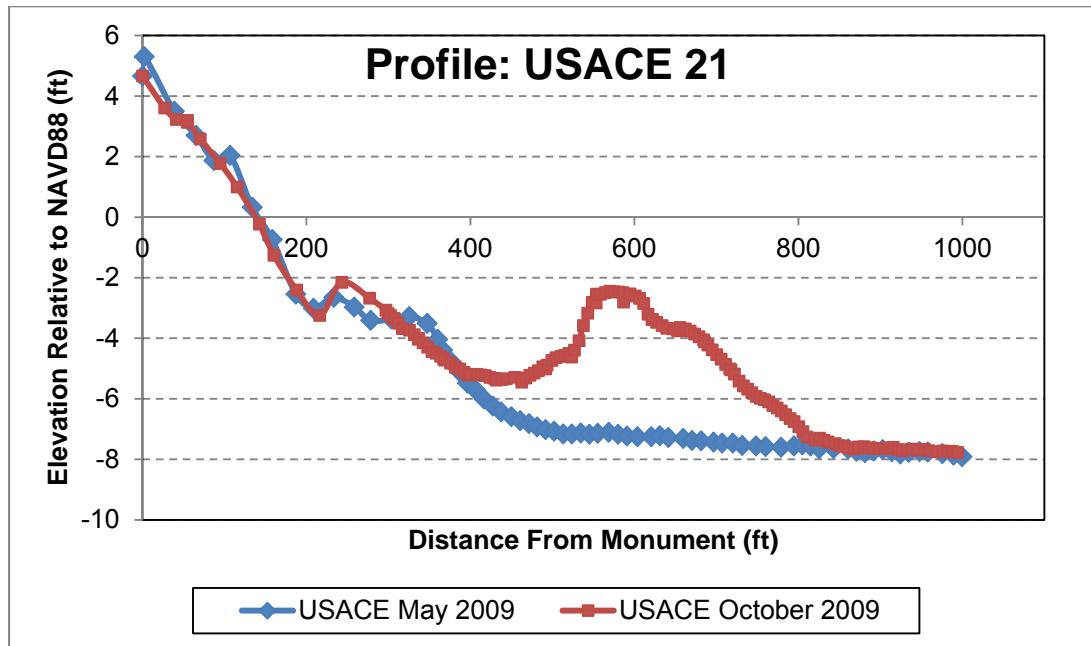


Figure F22. Beach Profile at USACE 21.

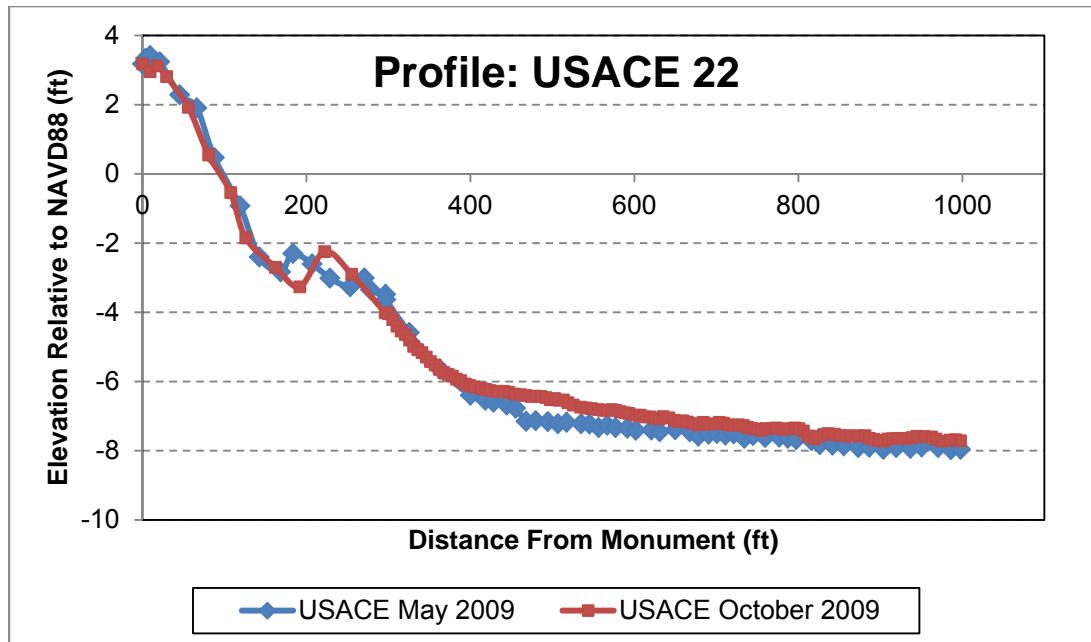


Figure F23. Beach Profile at USACE 22.

Appendix F. (Continued)

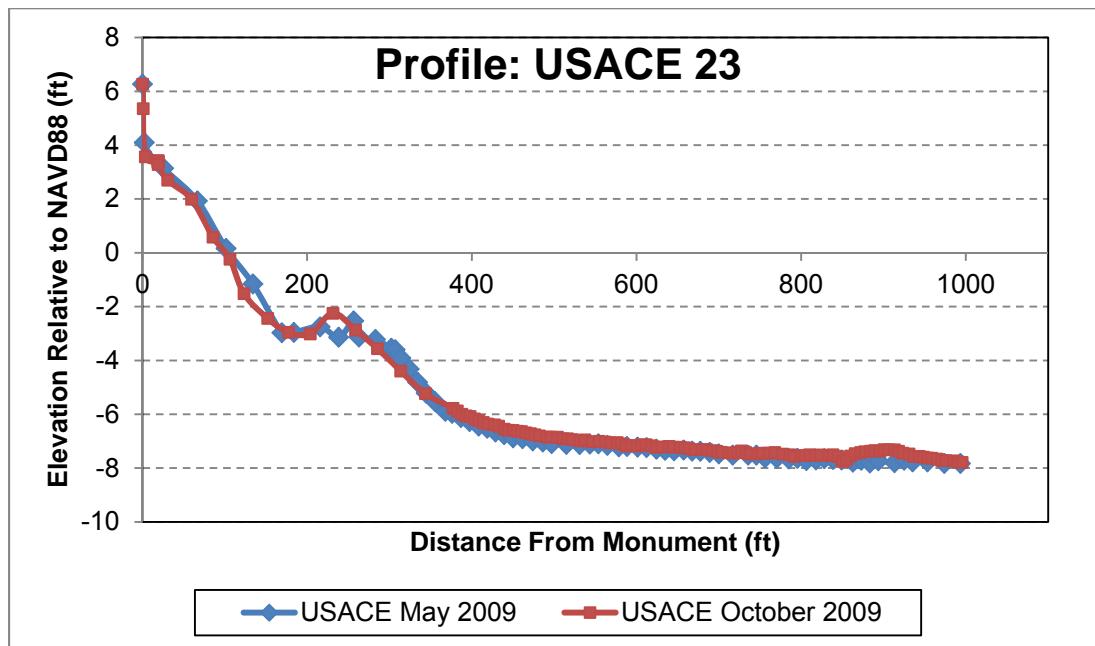


Figure F24. Beach Profile at USACE 23.

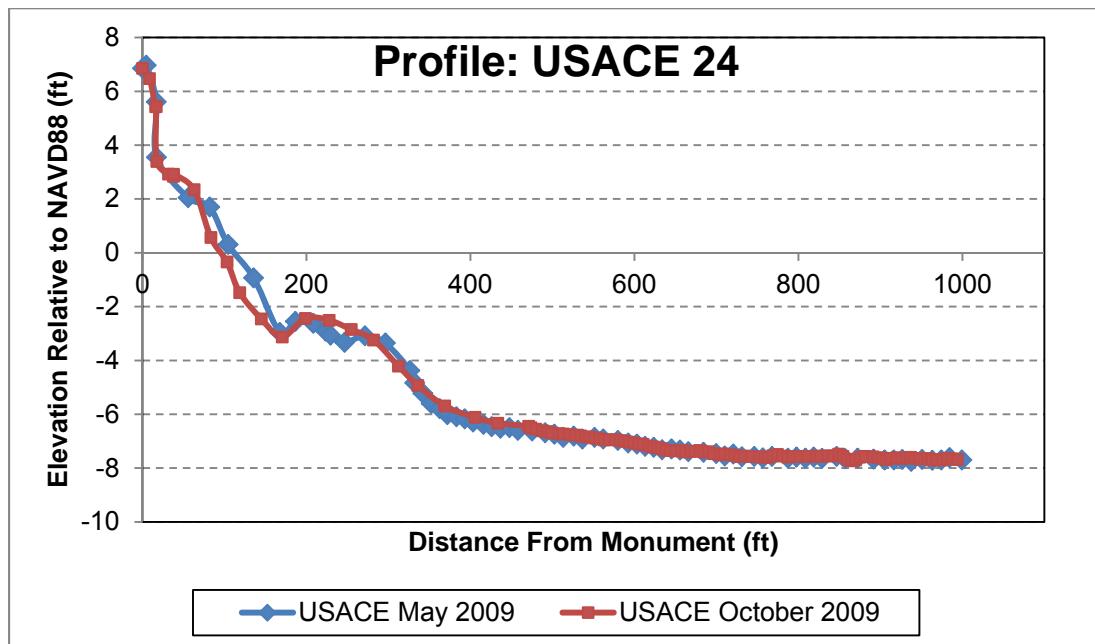


Figure F25. Beach Profile at USACE 24.

Appendix F. (Continued)

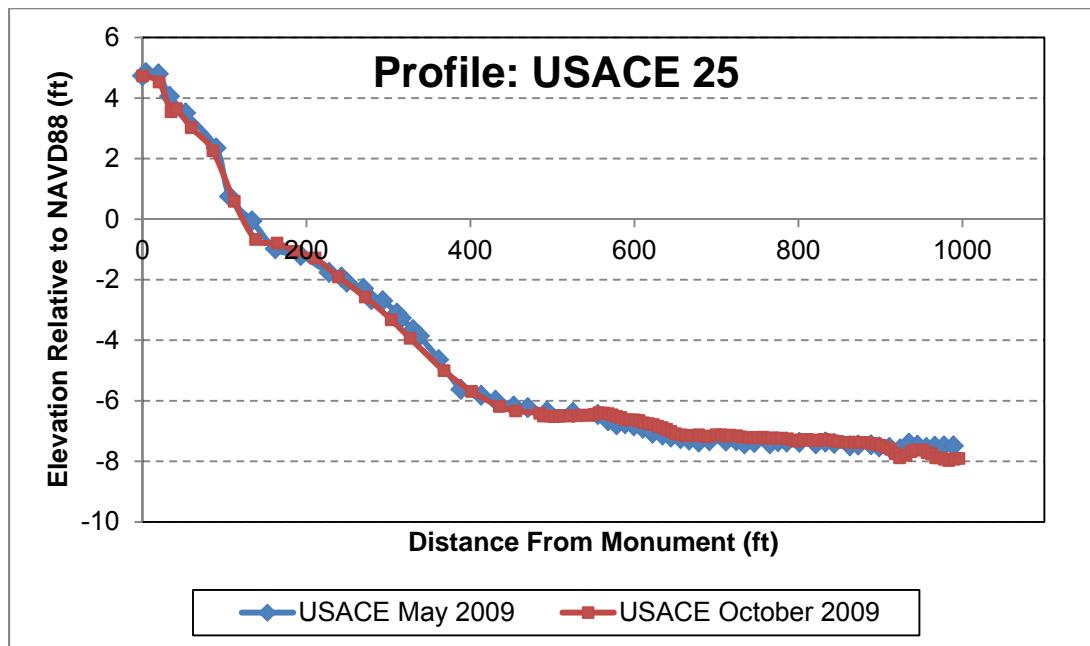


Figure F26. Beach Profile at USACE 25.

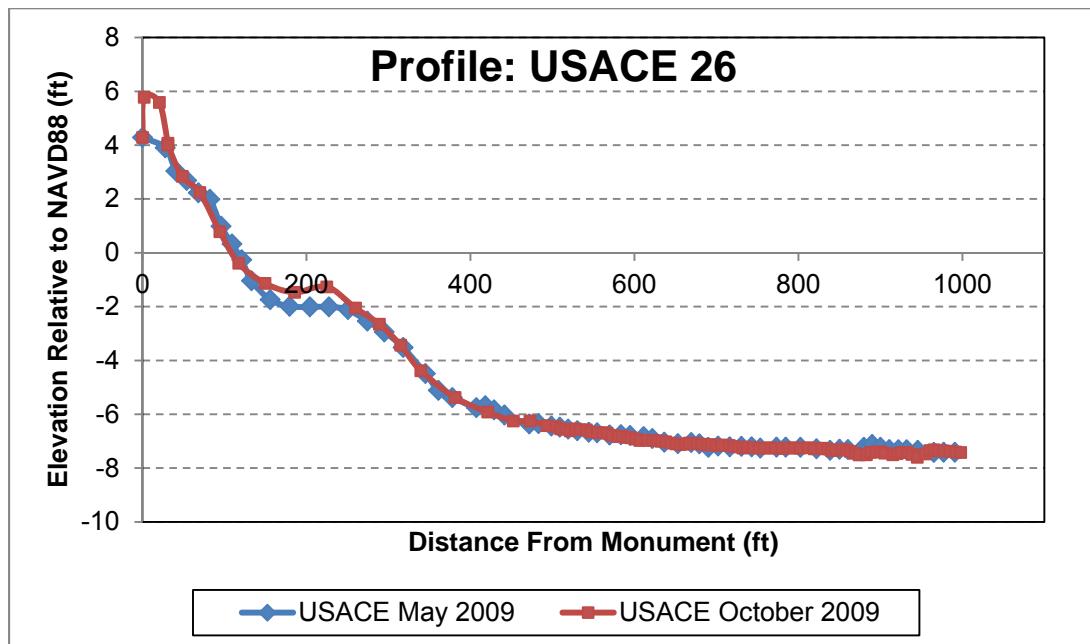


Figure F27. Beach Profile at USACE 26.

Appendix F. (Continued)

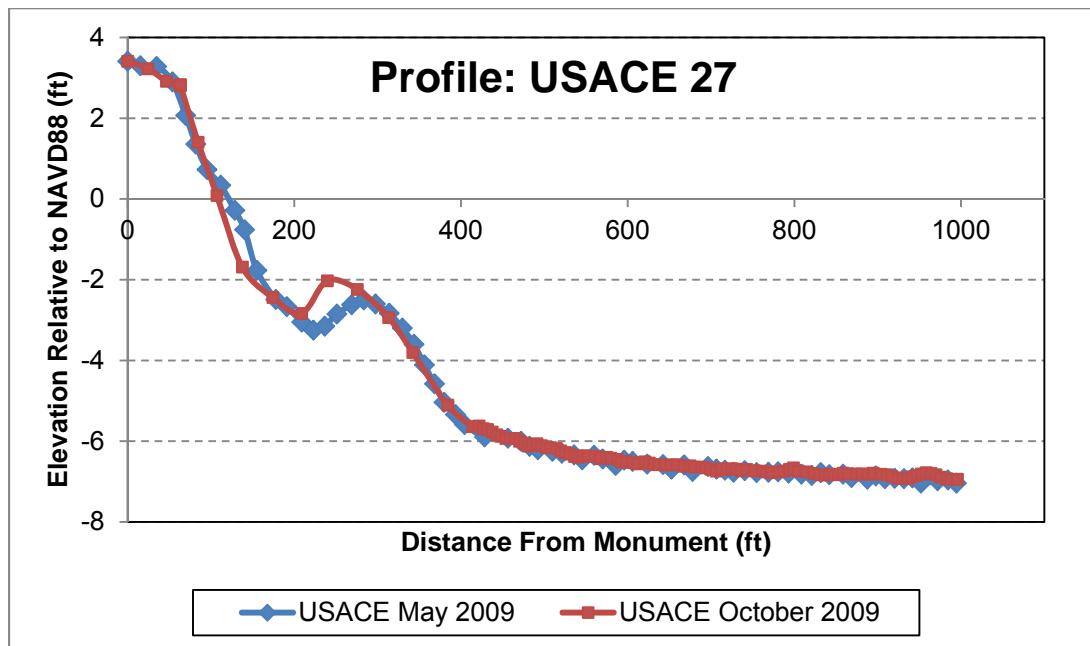


Figure F28. Beach Profile at USACE 27.

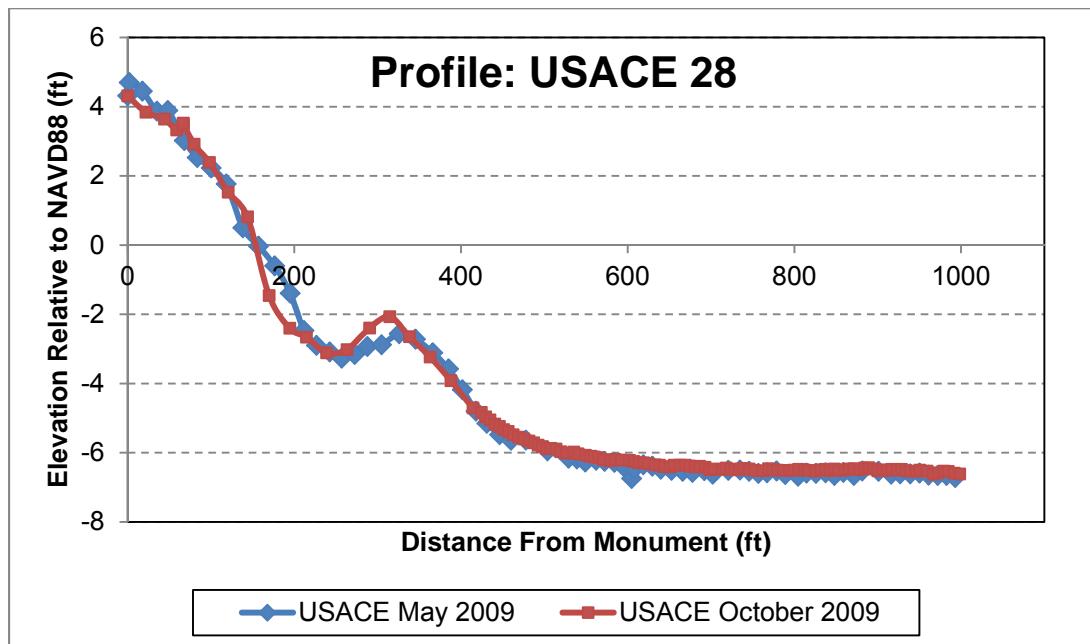


Figure F29. Beach Profile at USACE 28.

Appendix F. (Continued)

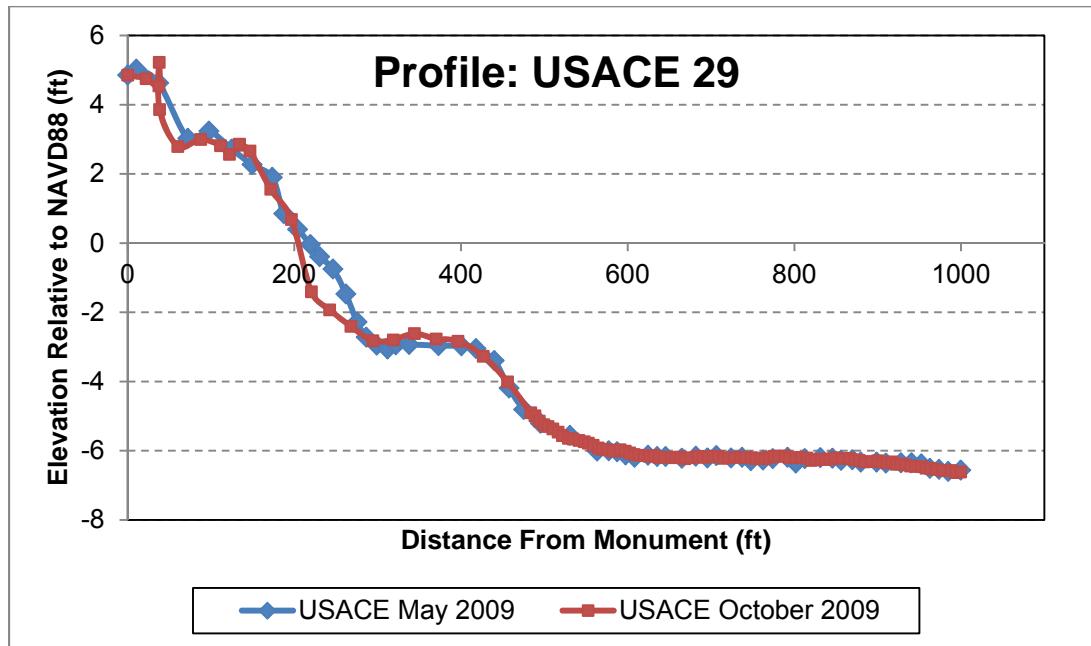


Figure F30. Beach Profile at USACE 29.

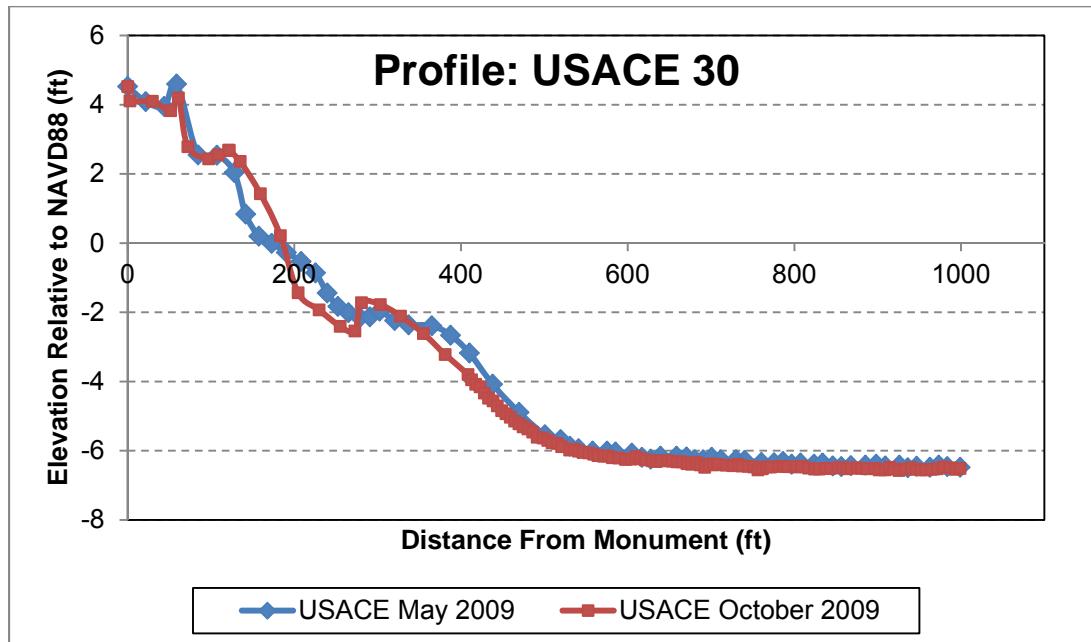


Figure F31. Beach Profile at USACE 30.

Appendix F. (Continued)

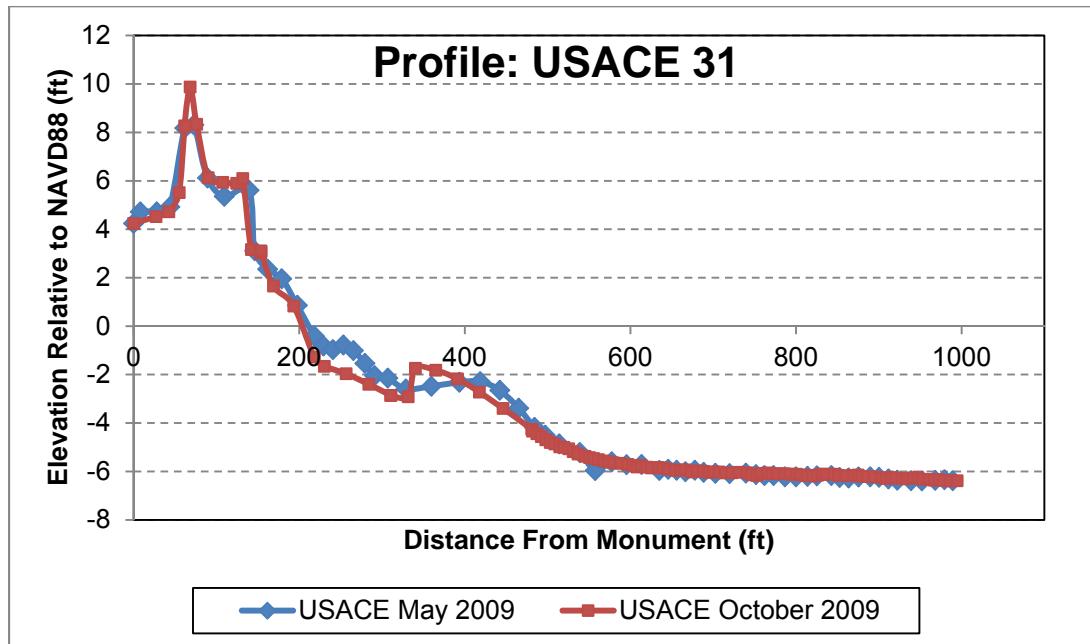


Figure F32. Beach Profile at USACE 31.

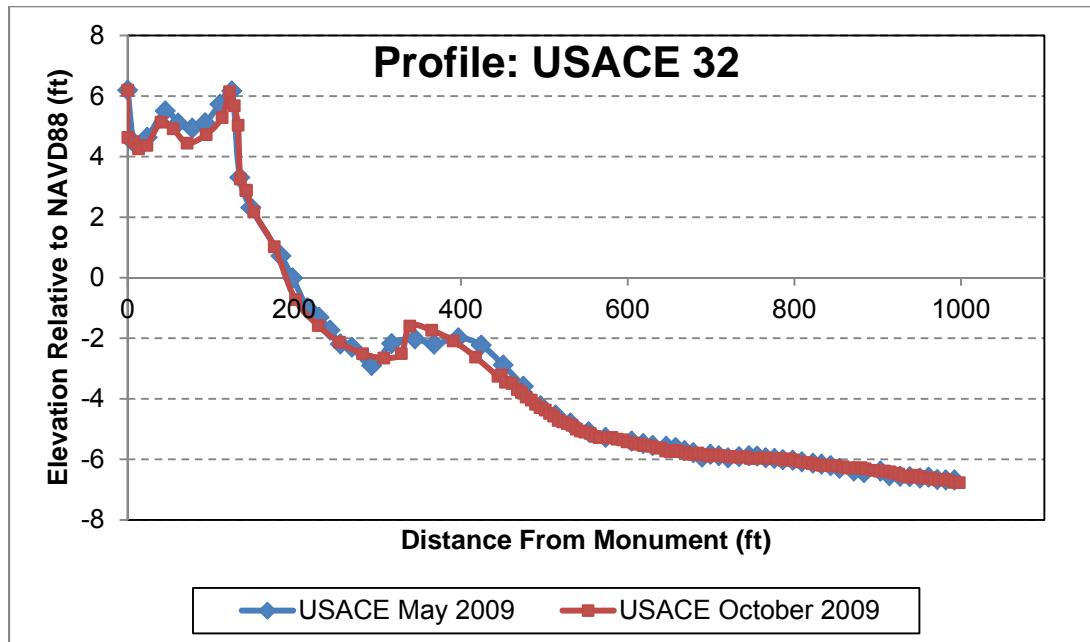


Figure F33. Beach Profile at USACE 32.

Appendix G: USF Survey Data

The following appendix includes beach profiles created from survey data recorded by USF in April 2010 and October 2010. Figure G1 is a map showing the location of each beach profile. All elevations are relative to NAVD88, and all distances are relative to a monument.

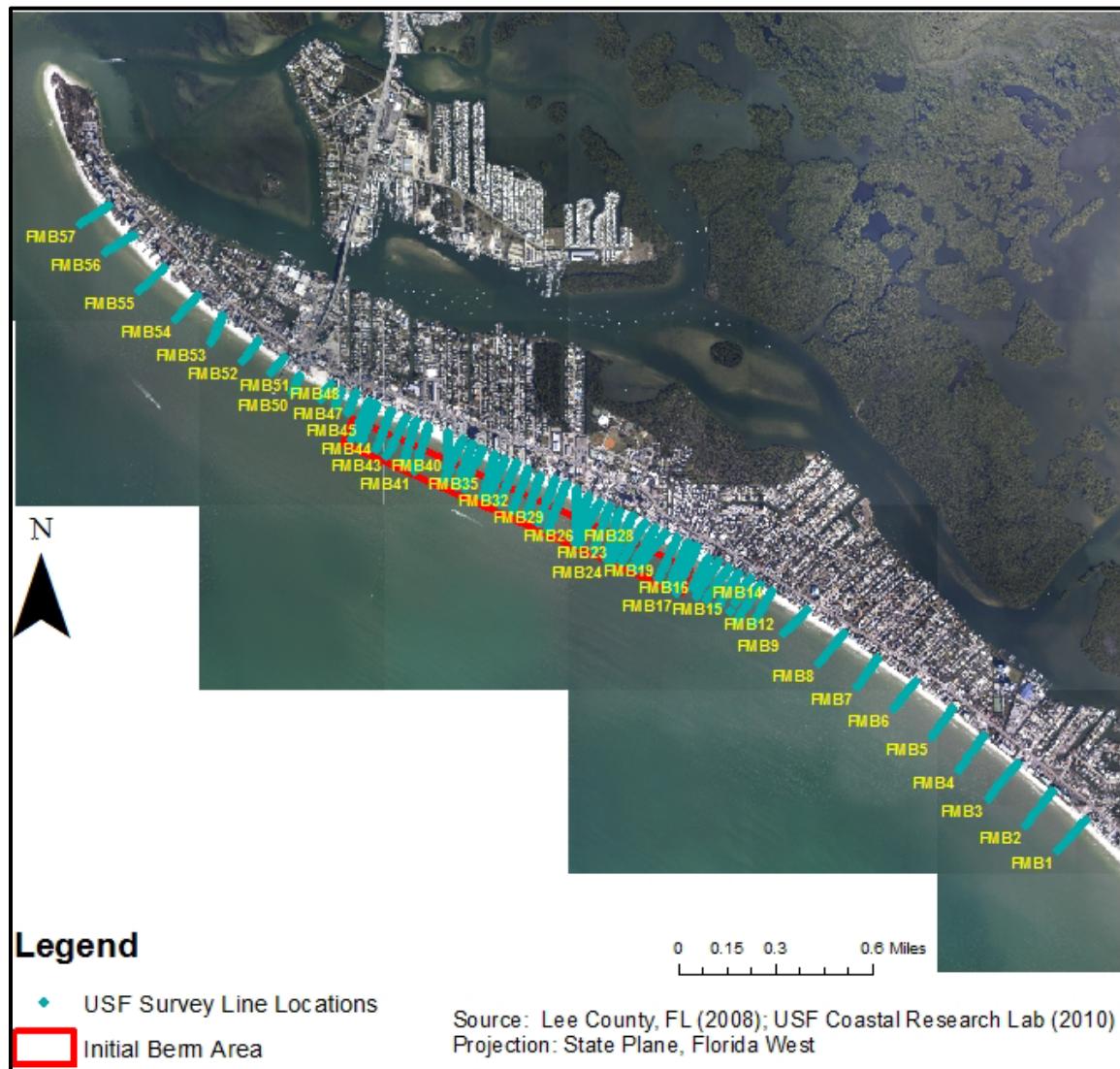


Figure G1. USF Survey Line Locations.

Appendix G. (Continued)

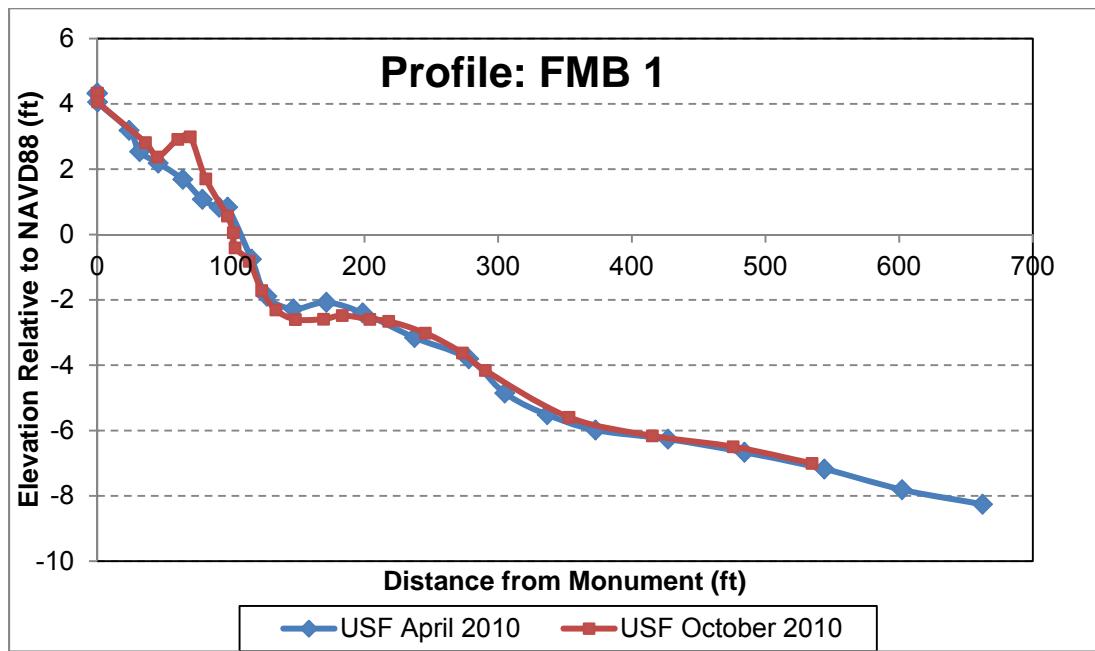


Figure G2. Beach Profile at FMB 1.

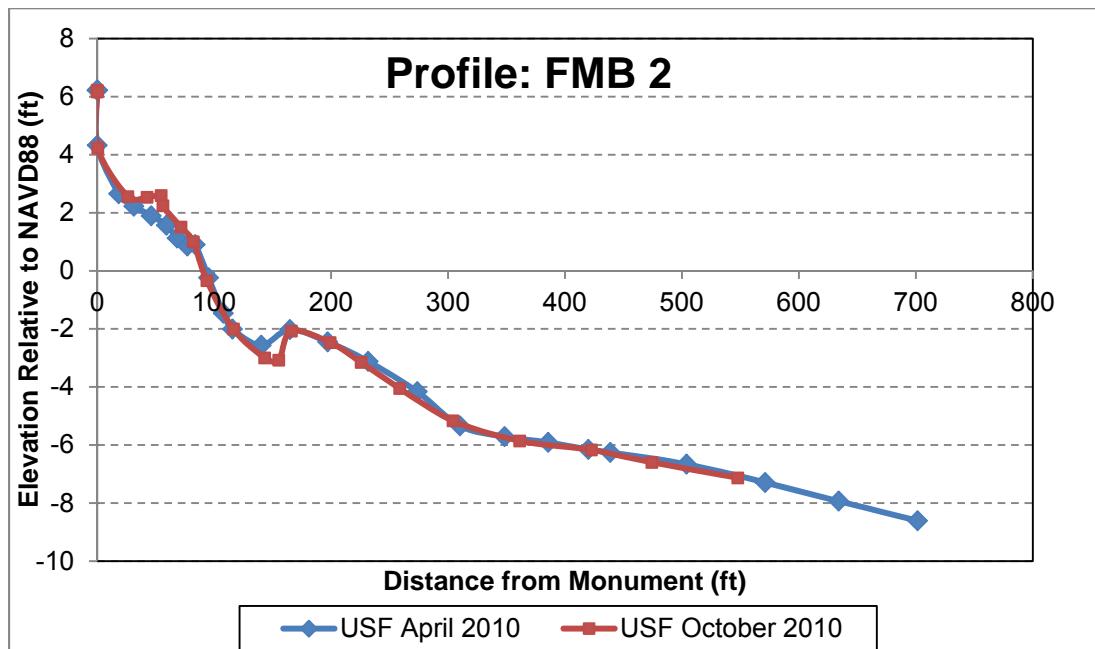


Figure G3. Beach Profile at FMB 2.

Appendix G. (Continued)

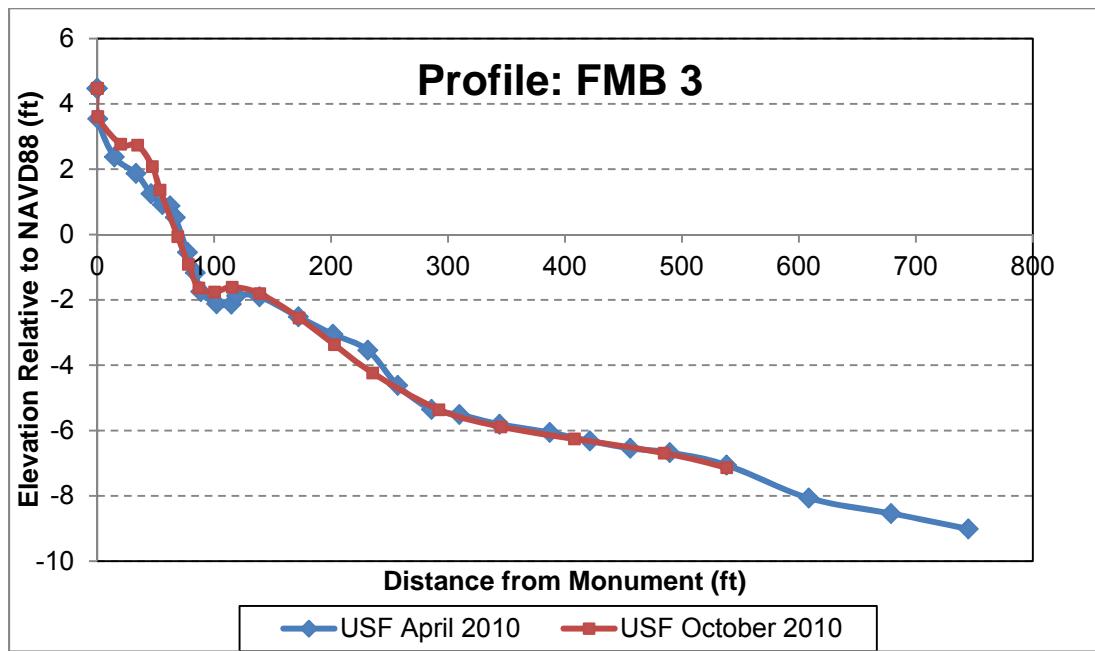


Figure G4. Beach Profile at FMB 3.

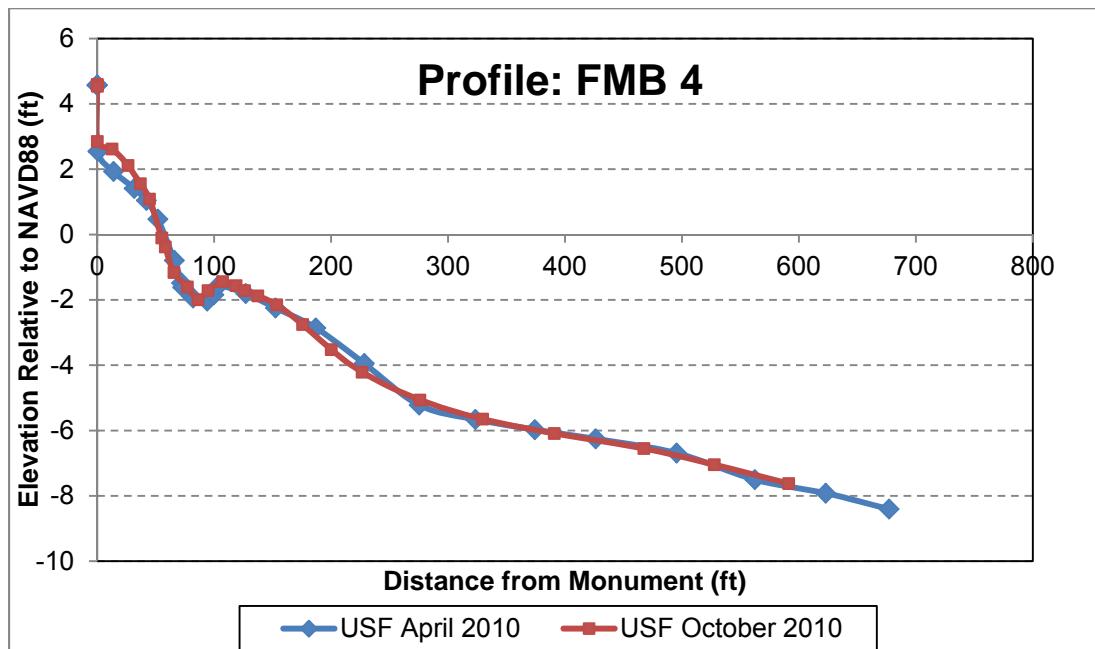


Figure G5. Beach Profile at FMB 4.

Appendix G. (Continued)

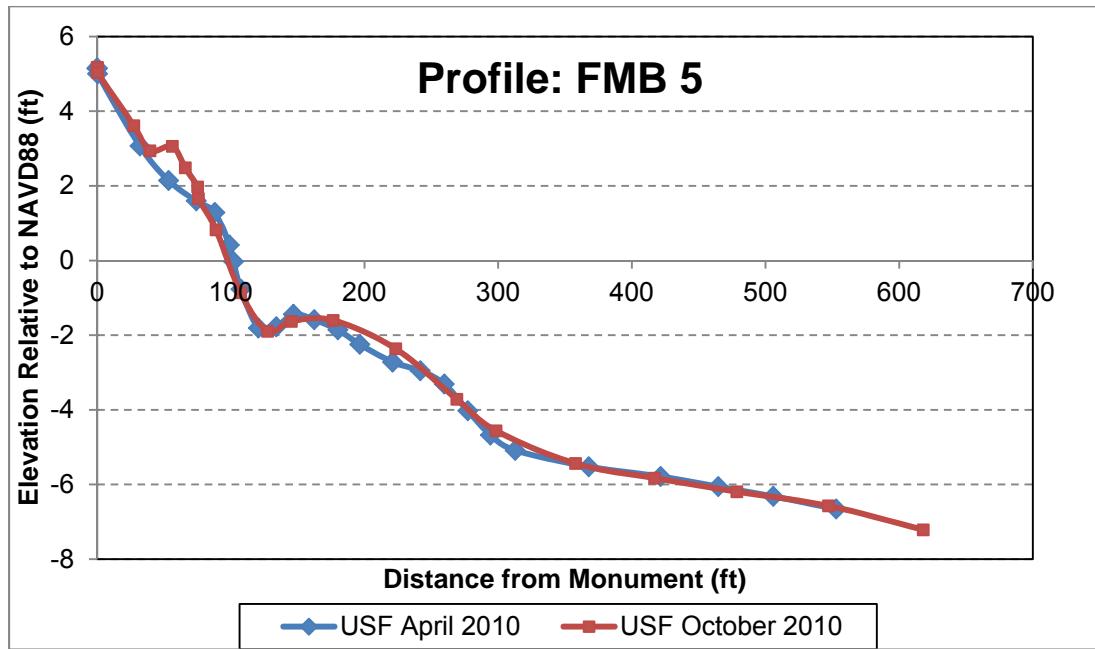


Figure G6. Beach Profile at FMB 5.

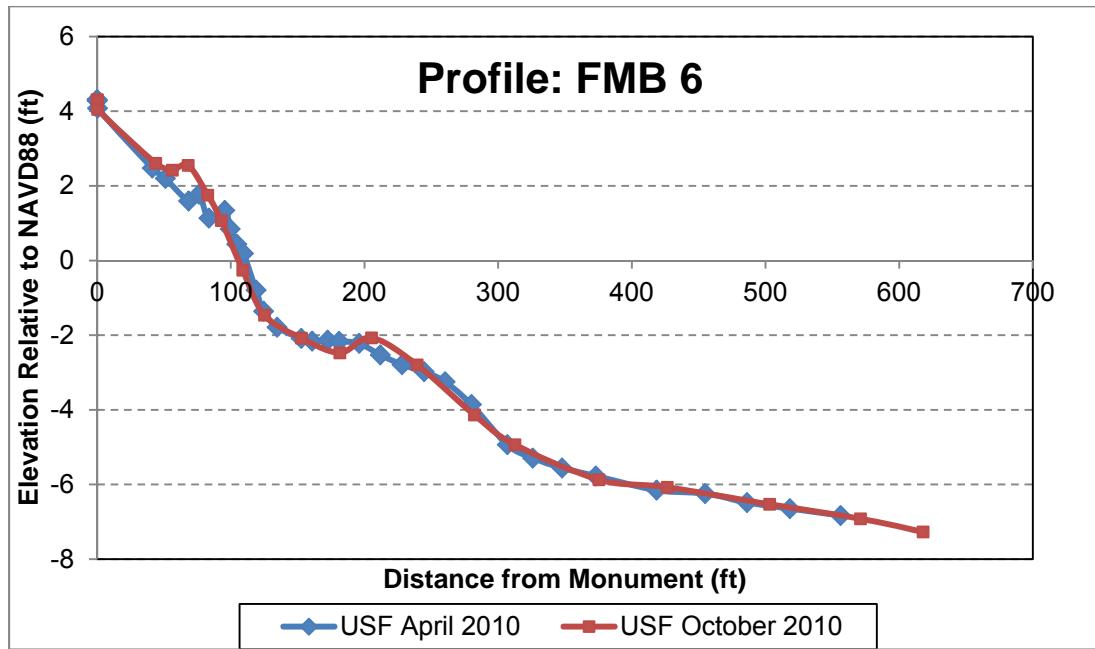


Figure G7. Beach Profile at FMB 6.

Appendix G. (Continued)

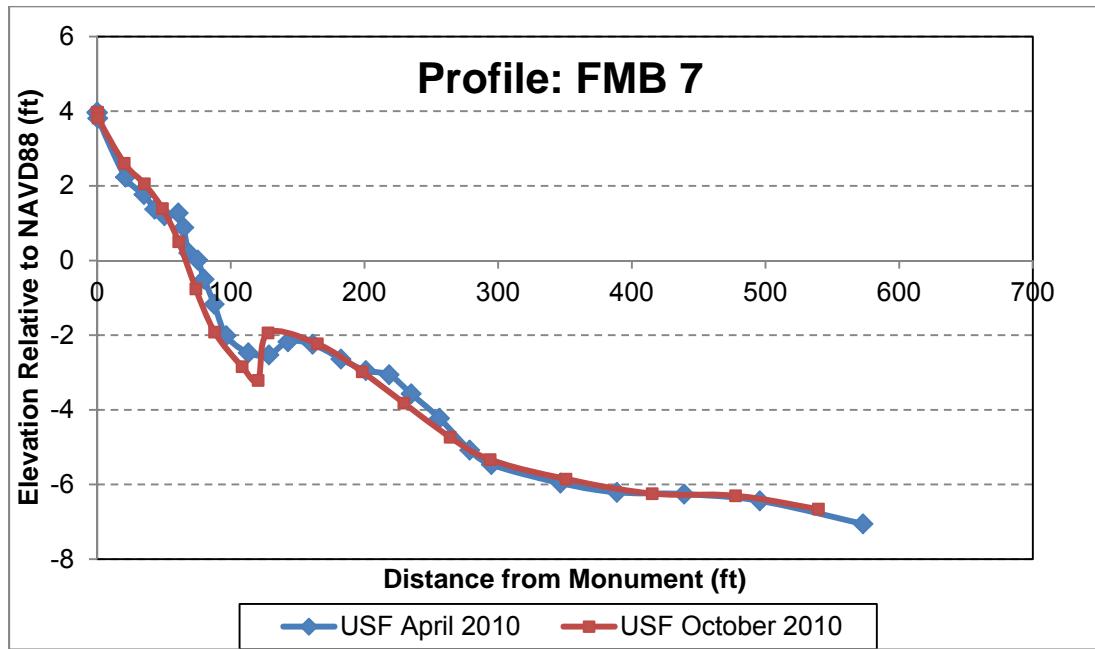


Figure G8. Beach Profile at FMB 7.

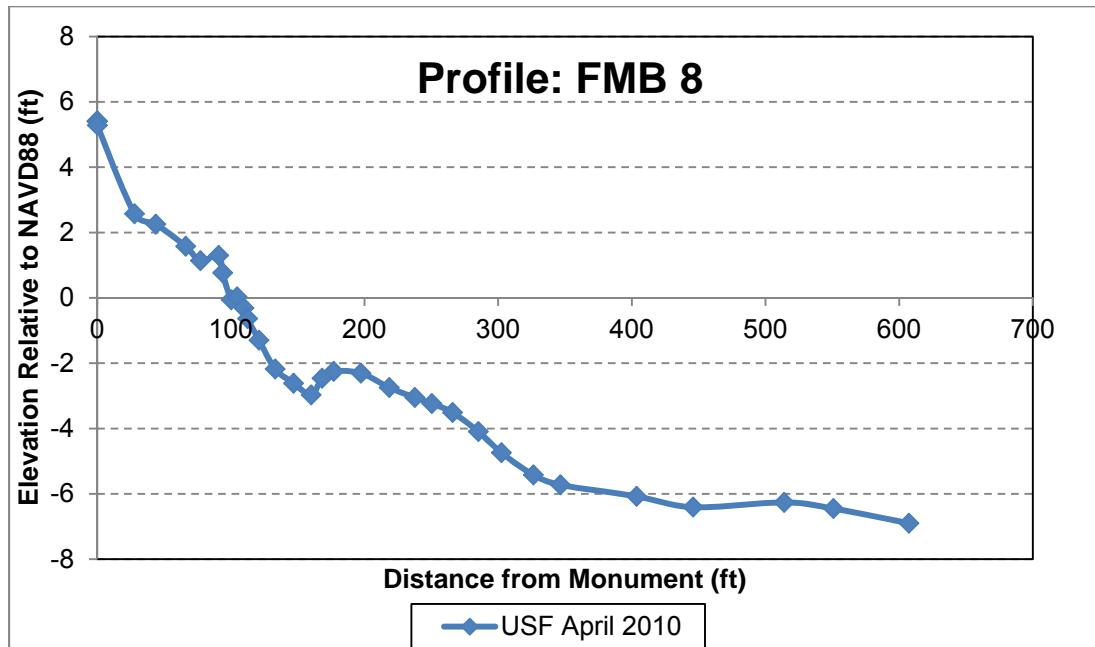


Figure G9. Beach Profile at FMB 8.

Appendix G. (Continued)

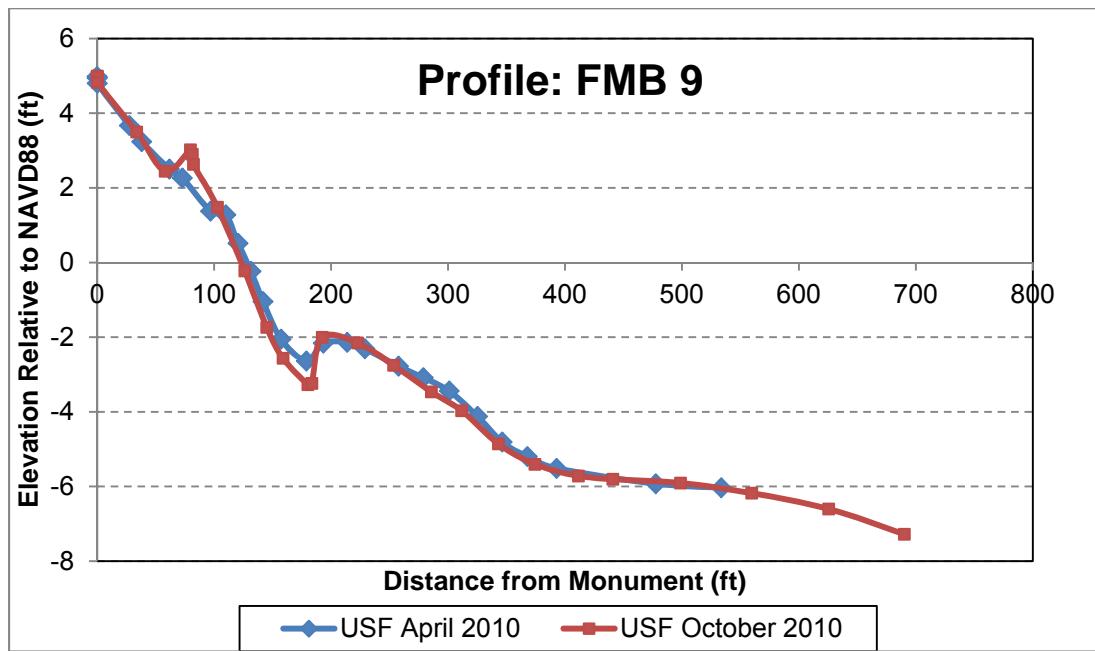


Figure G10. Beach Profile at FMB 9.

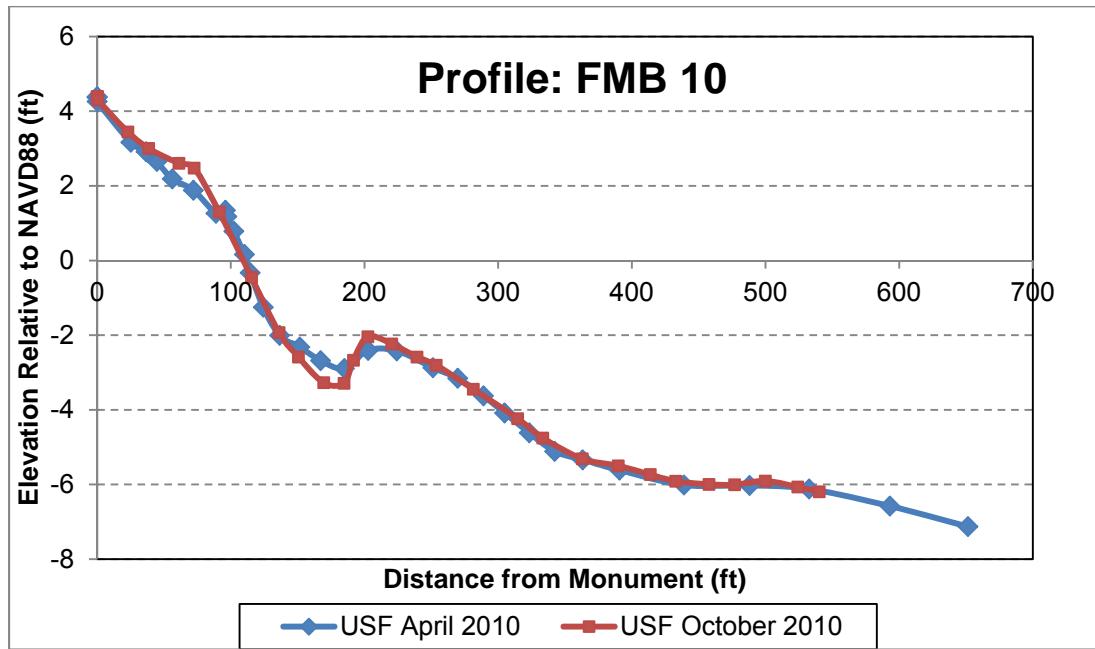


Figure G11. Beach Profile at FMB 10.

Appendix G. (Continued)

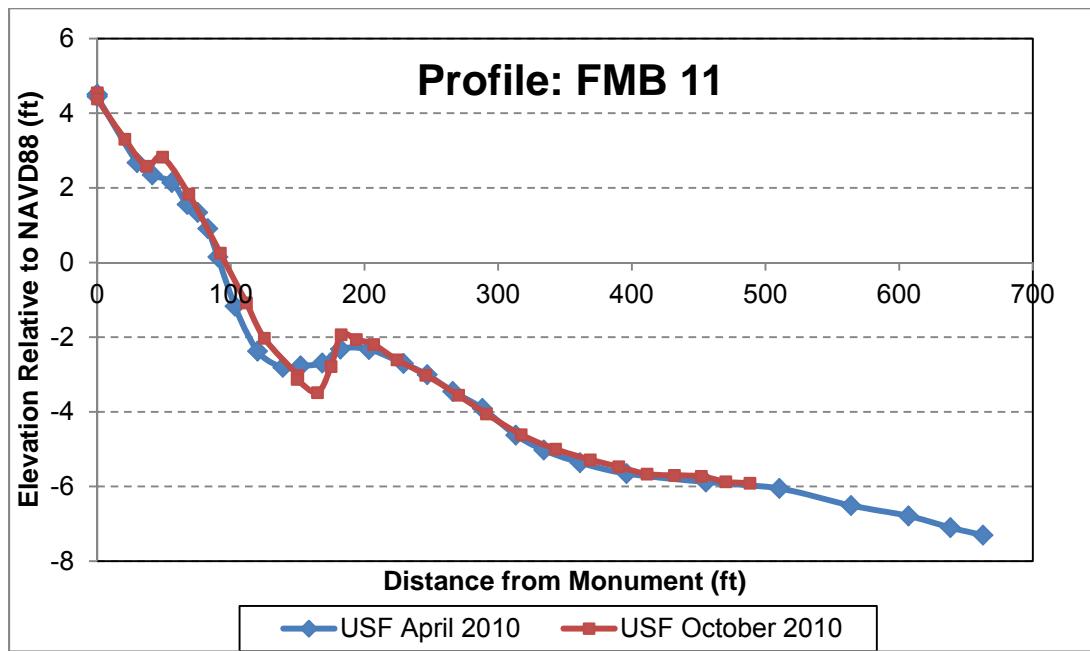


Figure G12. Beach Profile at FMB 11.

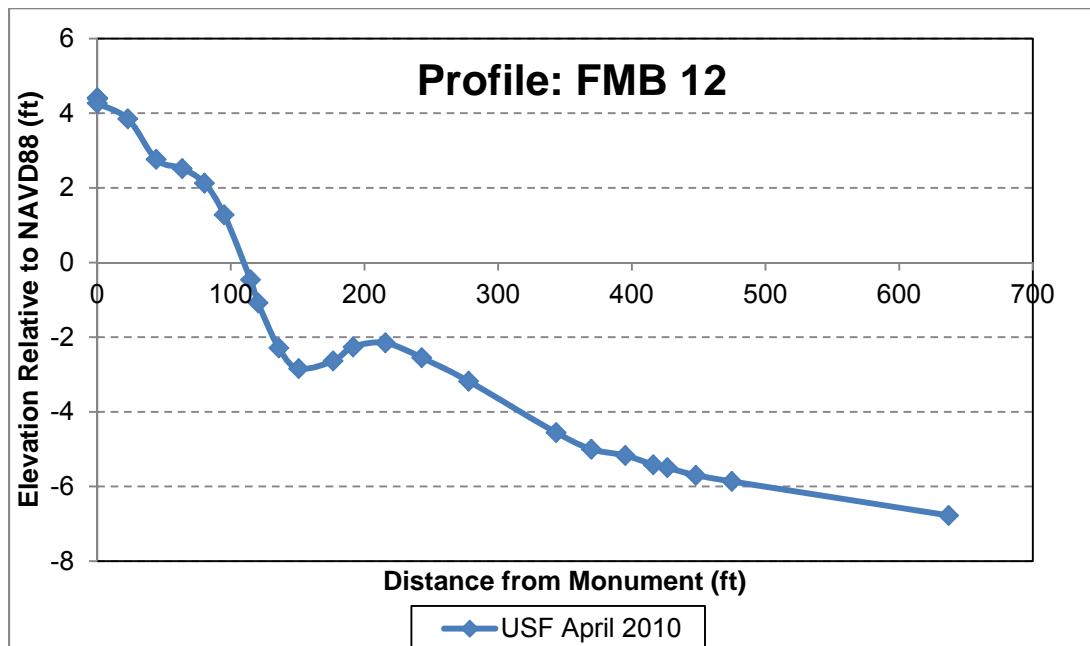


Figure G13. Beach Profile at FMB 12.

Appendix G. (Continued)

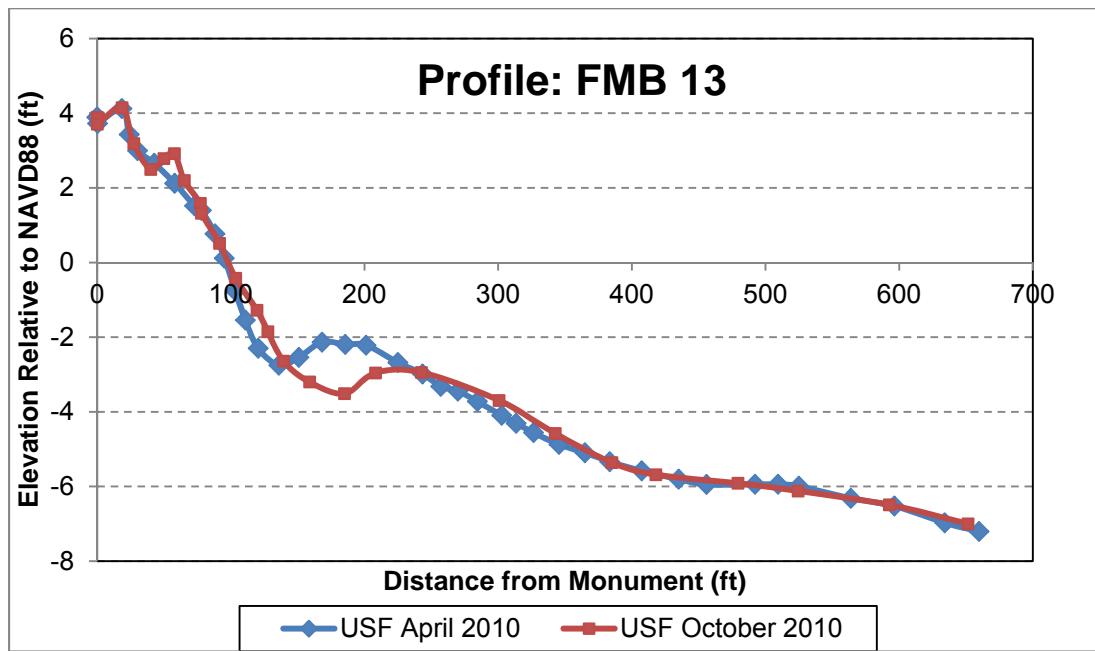


Figure G14. Beach Profile at FMB 13.

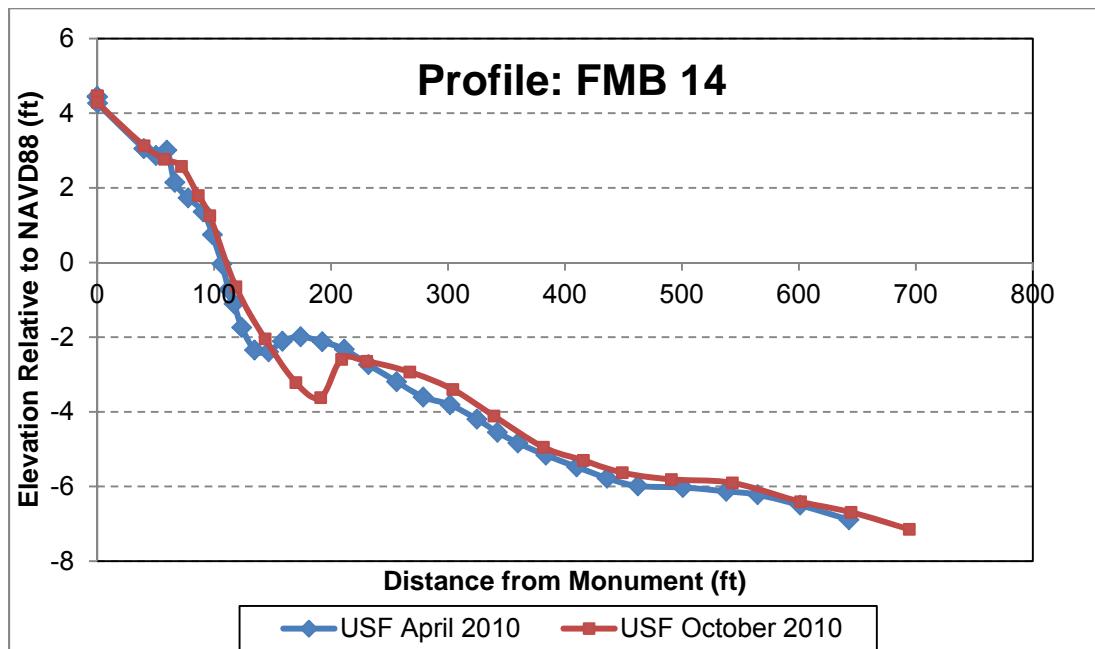


Figure G15. Beach Profile at FMB 14.

Appendix G. (Continued)

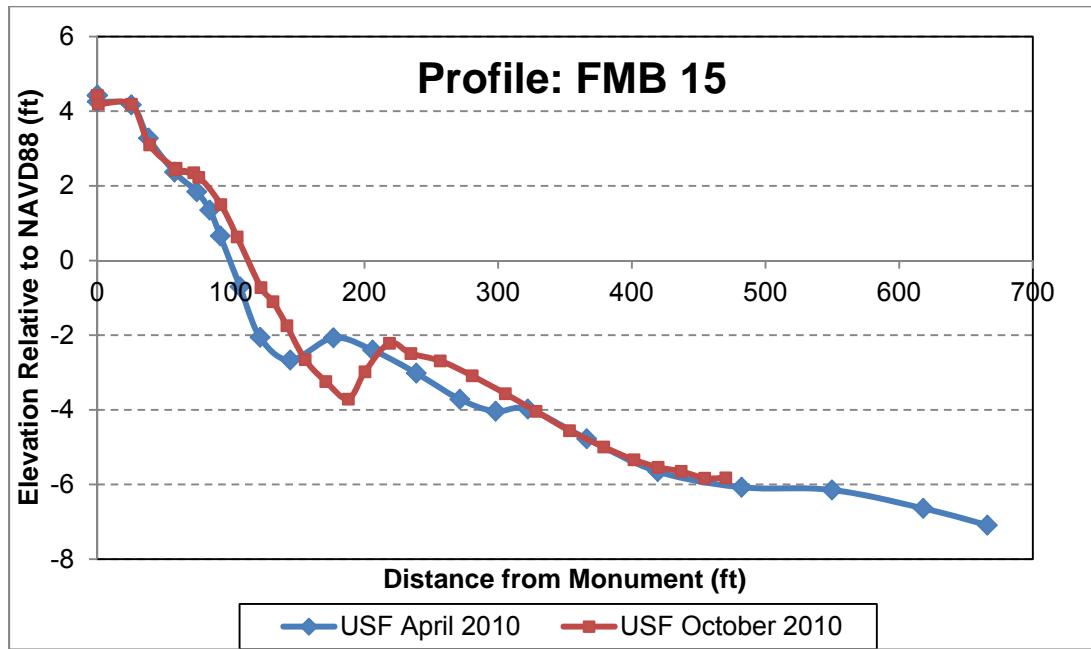


Figure G16. Beach Profile at FMB 15.

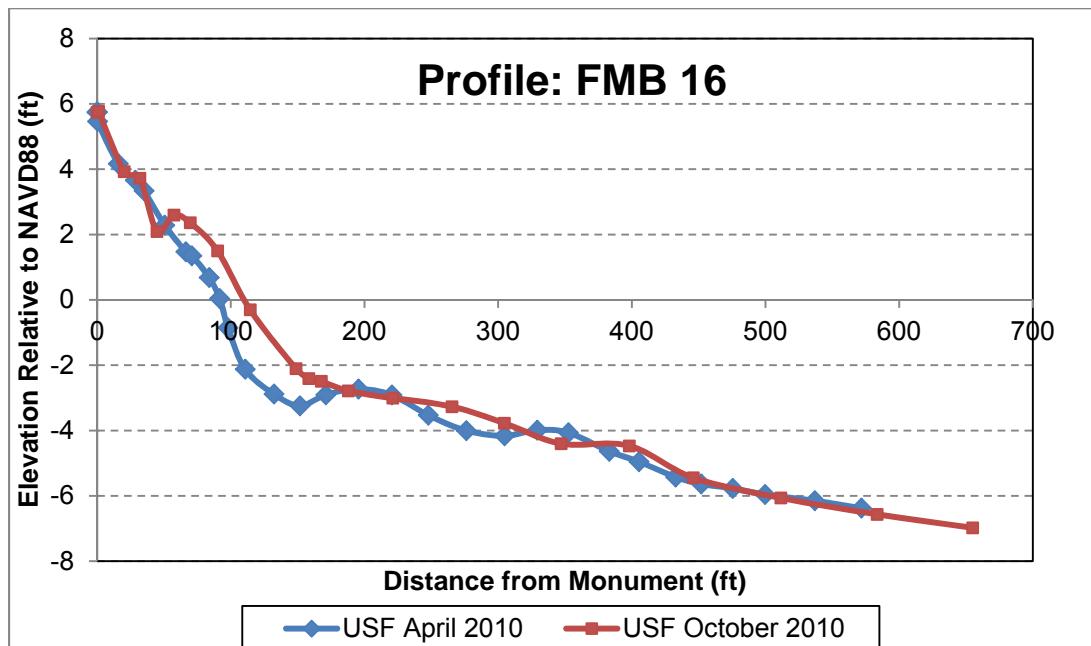


Figure G17. Beach Profile at FMB 16.

Appendix G. (Continued)

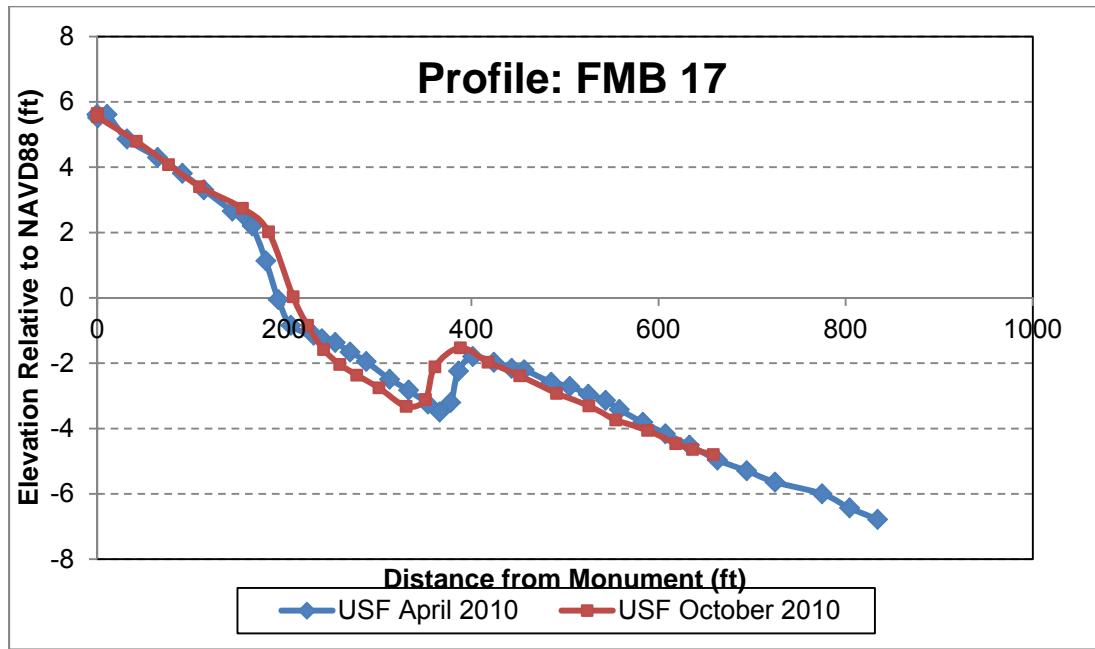


Figure G18. Beach Profile at FMB 17.

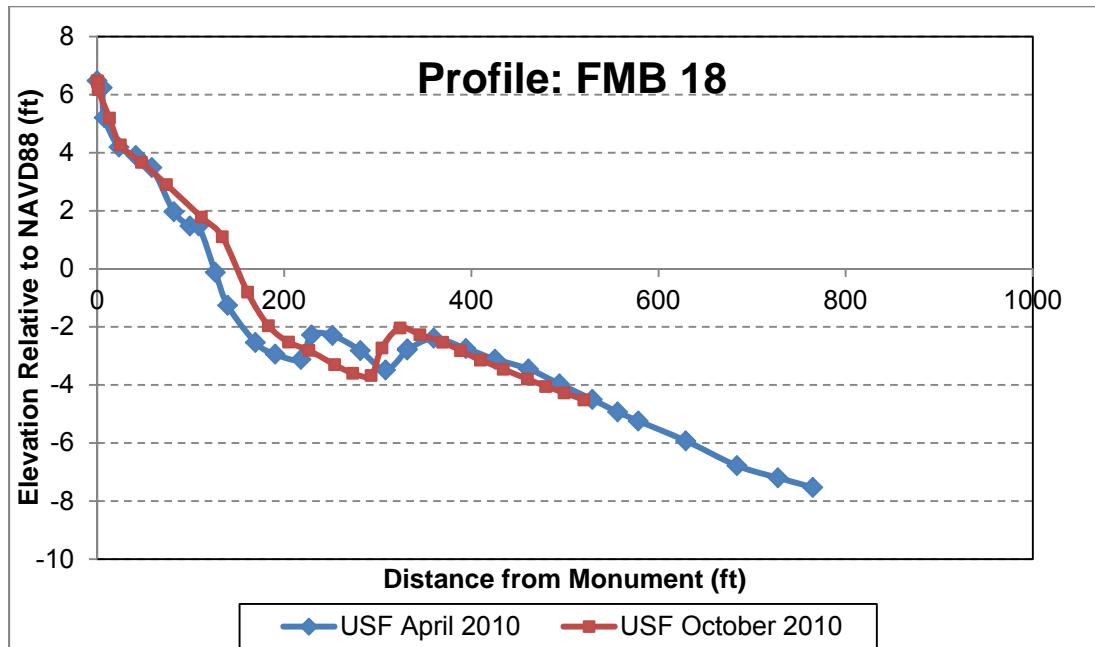


Figure G19. Beach Profile at FMB 18.

Appendix G. (Continued)

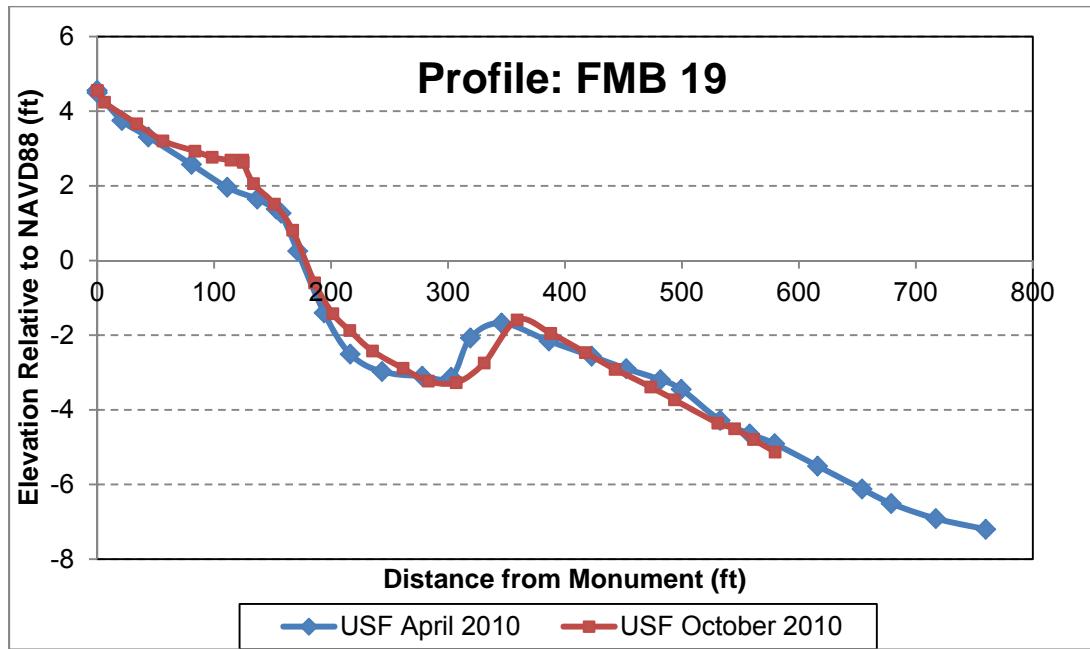


Figure G20. Beach Profile at FMB 19.

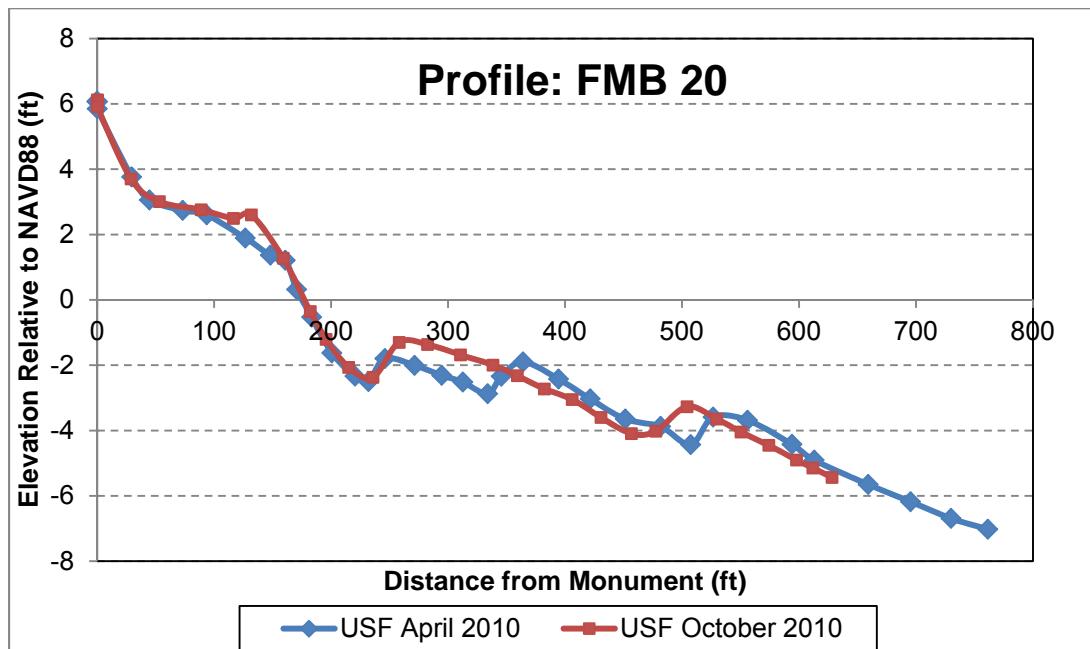


Figure G21. Beach Profile at FMB 20.

Appendix G. (Continued)

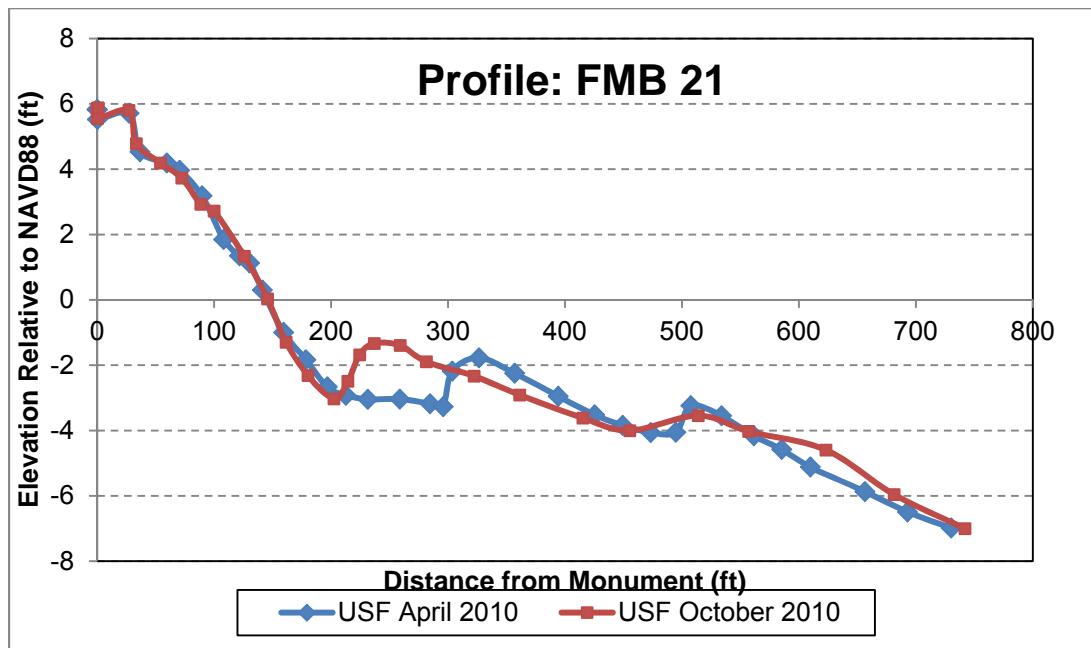


Figure G22. Beach Profile at FMB 21.

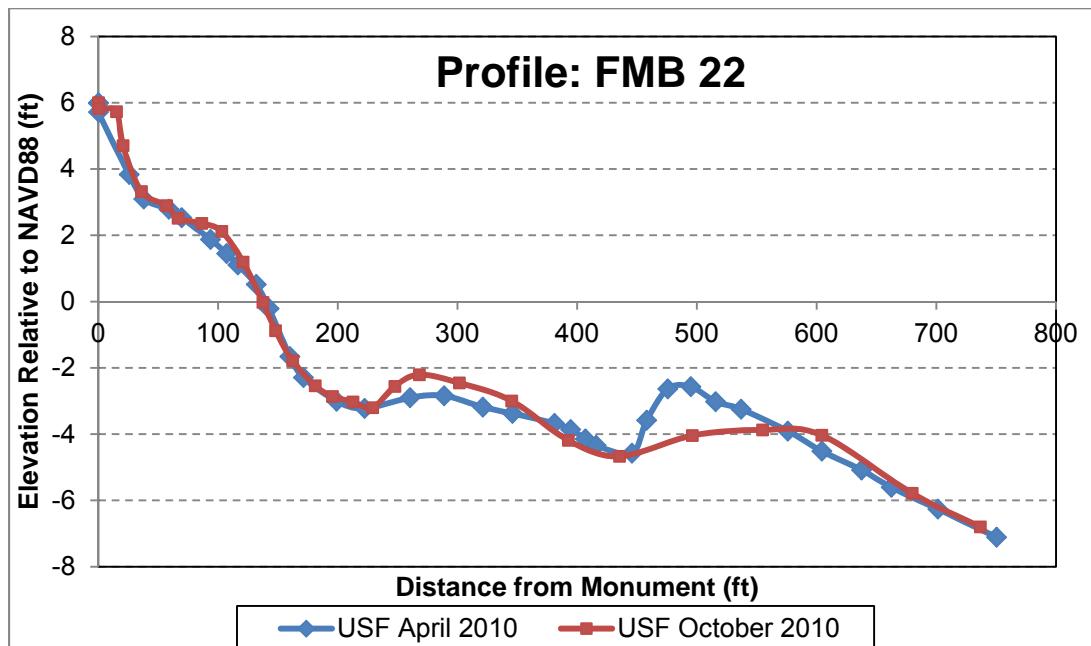


Figure G23. Beach Profile at FMB 22.

Appendix G. (Continued)

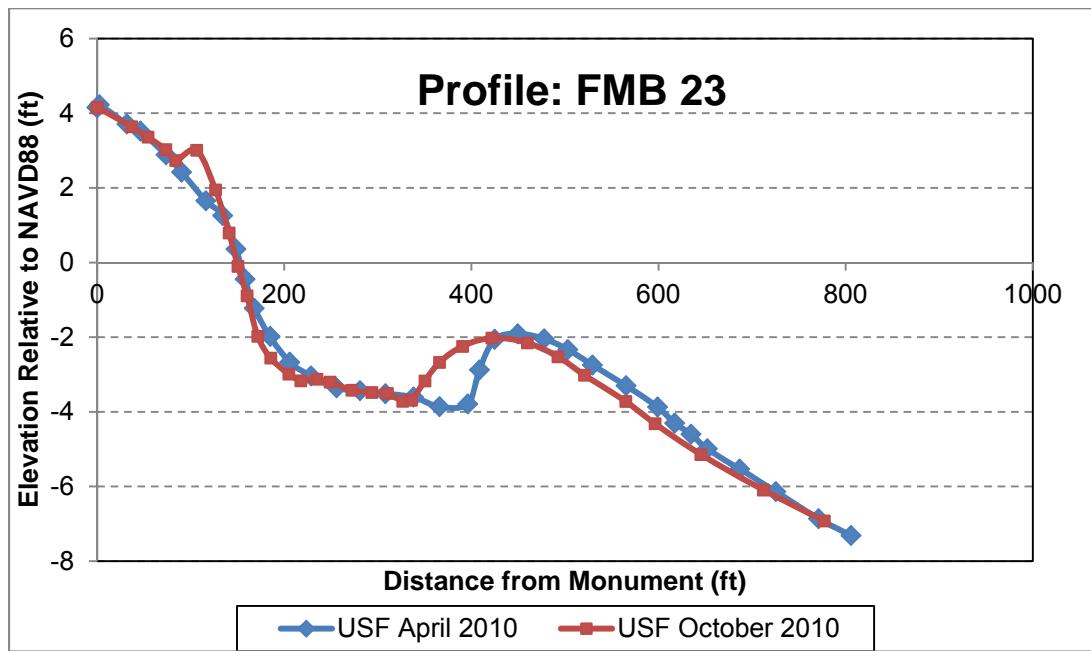


Figure G24. Beach Profile at FMB 23.

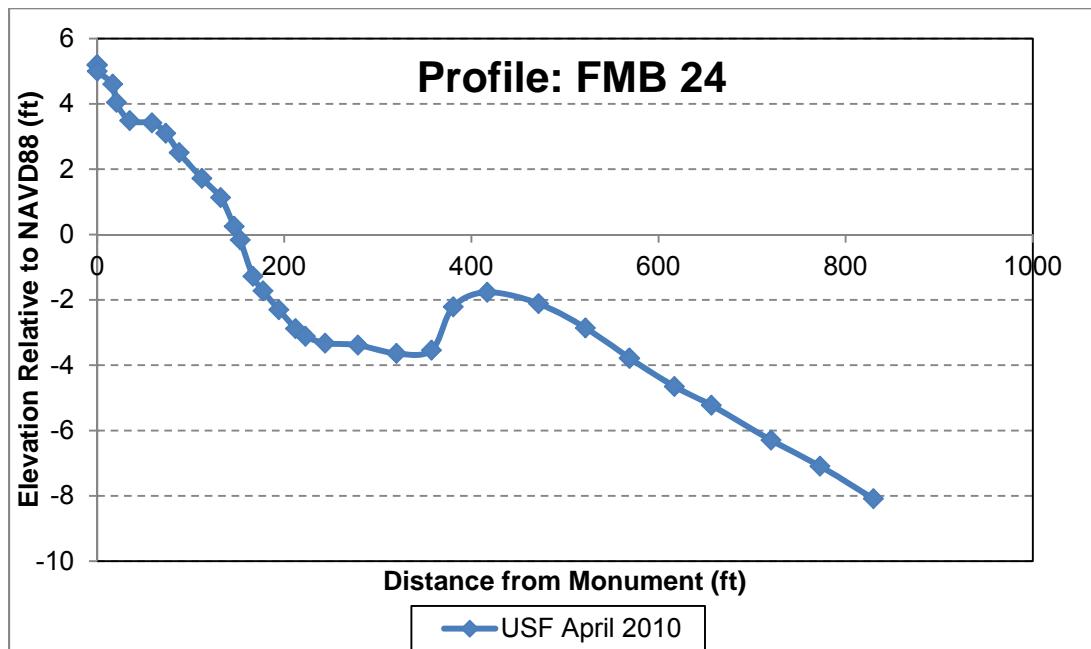


Figure G25. Beach Profile at FMB 24.

Appendix G. (Continued)

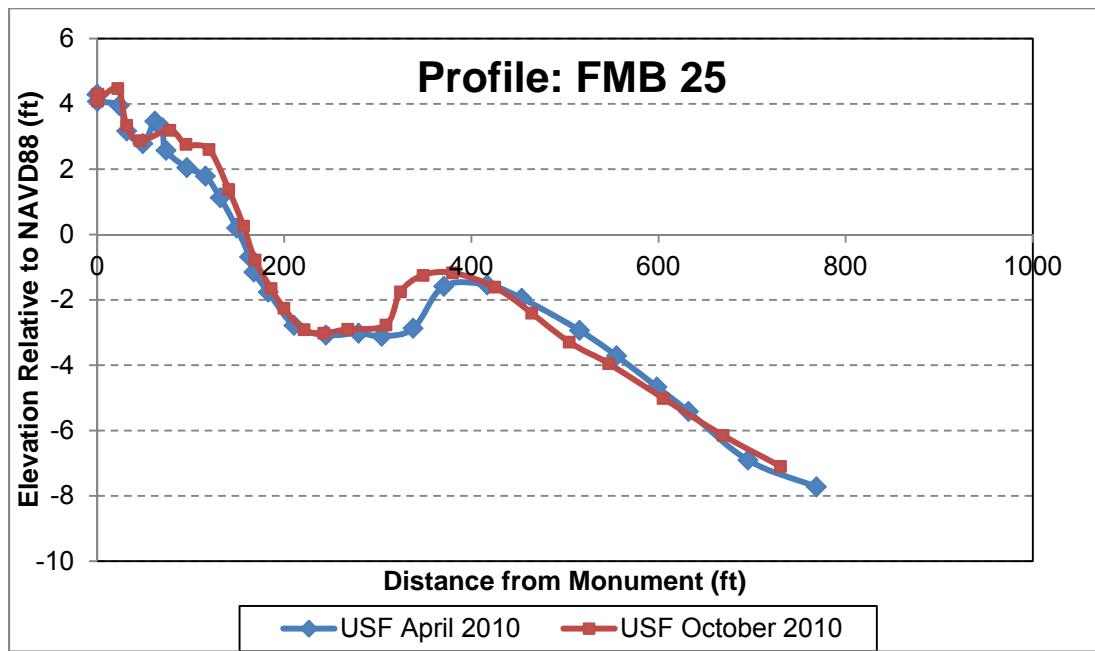


Figure G26. Beach Profile at FMB 25.

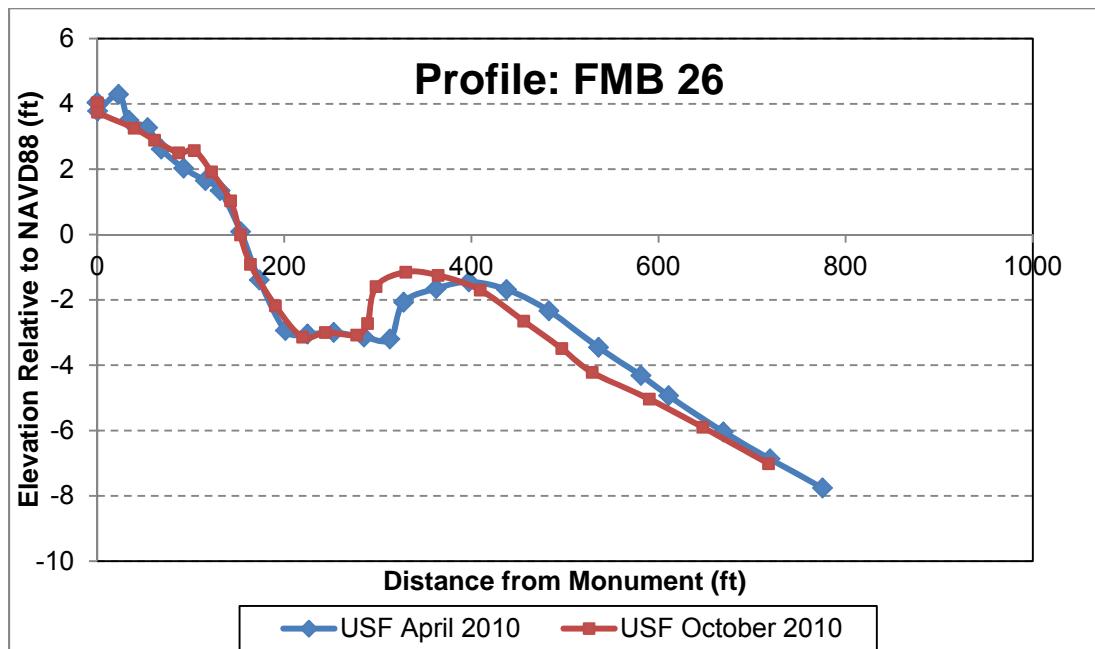


Figure G27. Beach Profile at FMB 26.

Appendix G. (Continued)

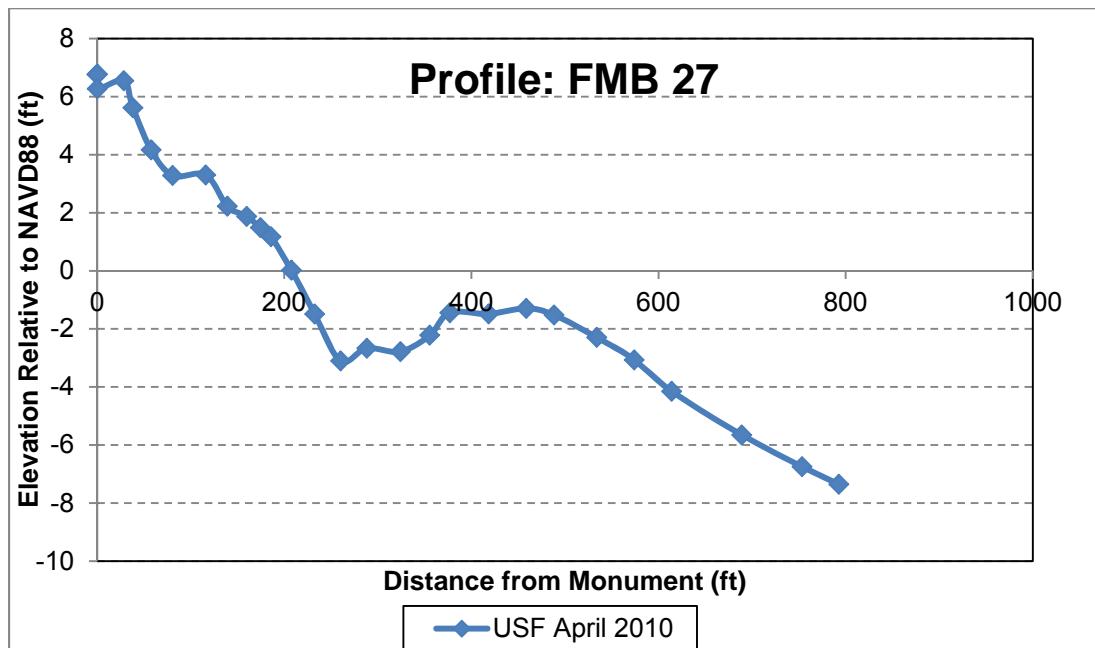


Figure G28. Beach Profile at FMB 27.

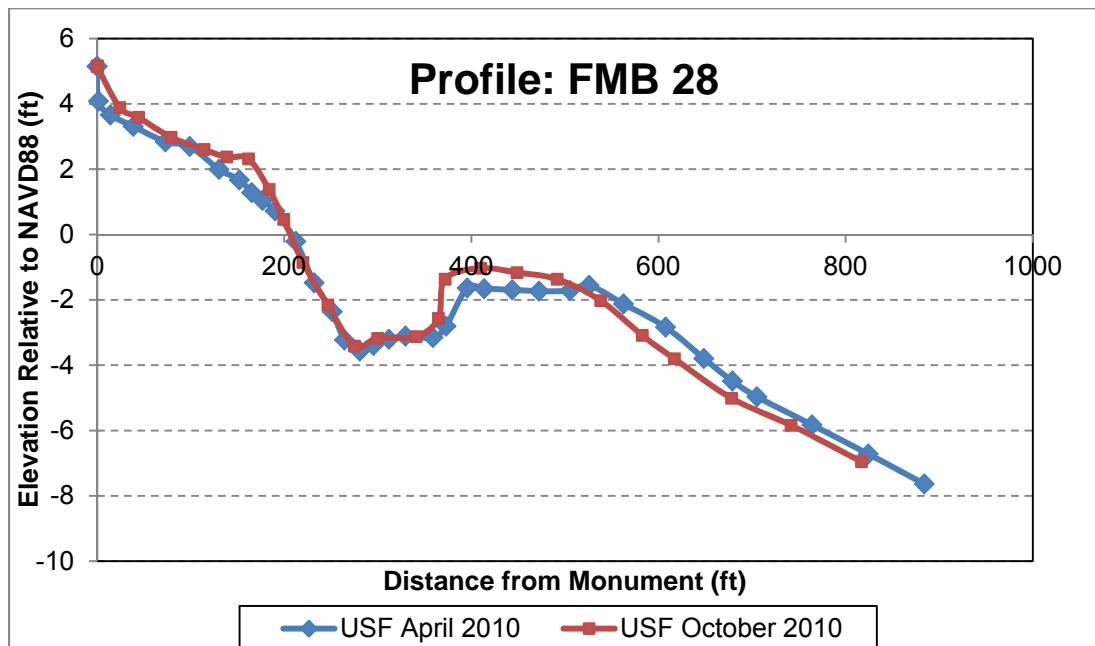


Figure G29. Beach Profile at FMB 28.

Appendix G. (Continued)

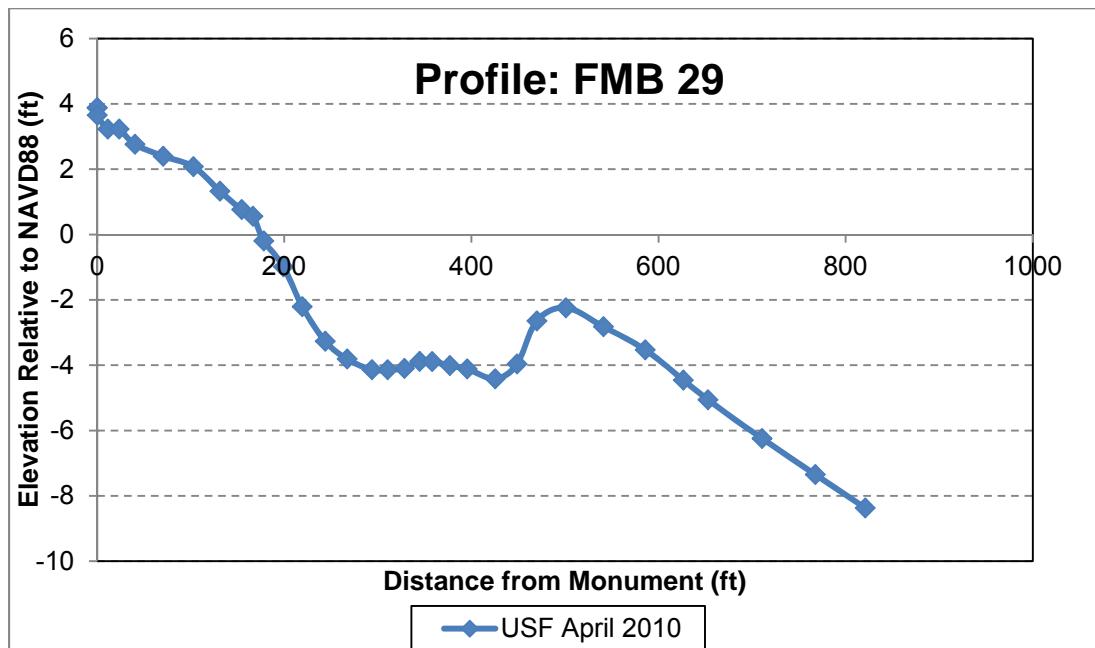


Figure G30. Beach Profile at FMB 29.

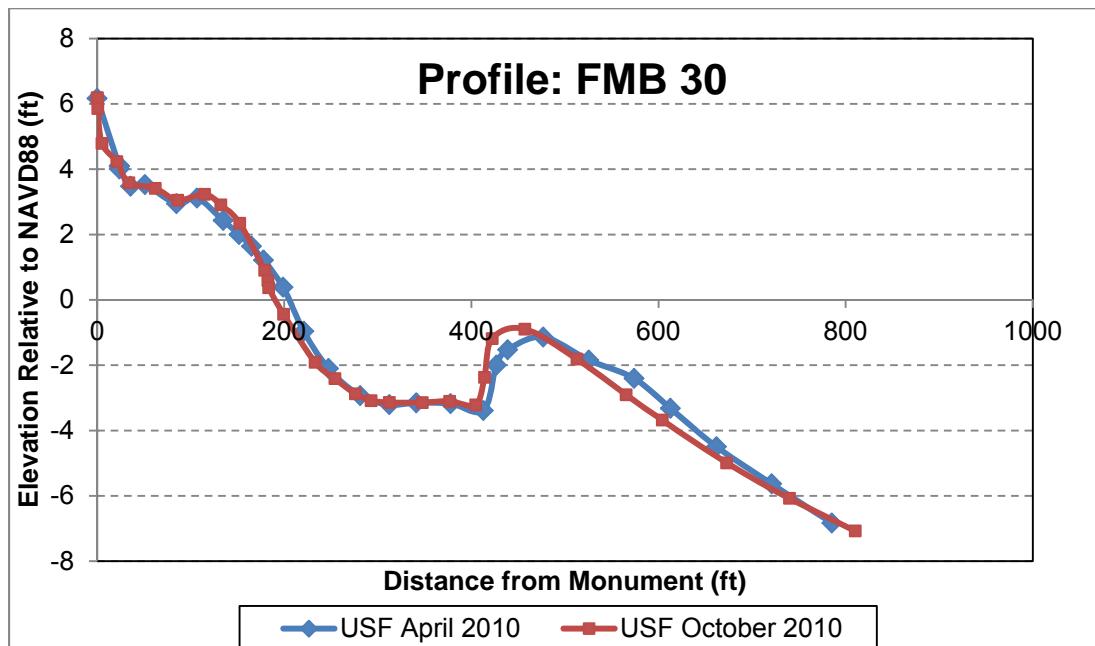


Figure G31. Beach Profile at FMB 30.

Appendix G. (Continued)

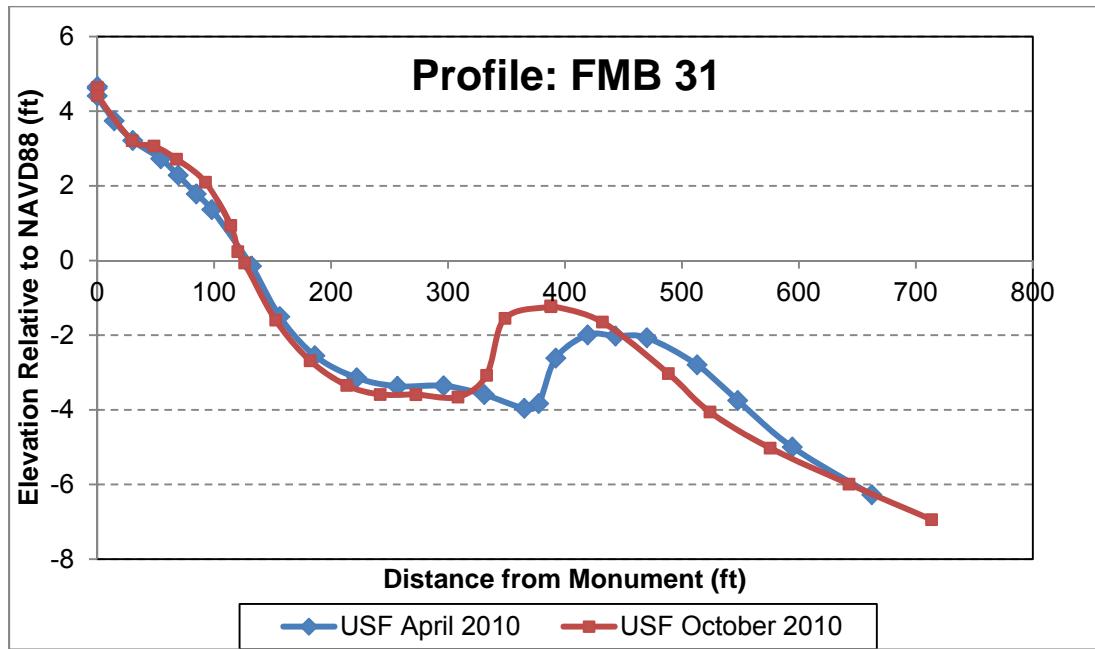


Figure G32. Beach Profile at FMB 31.

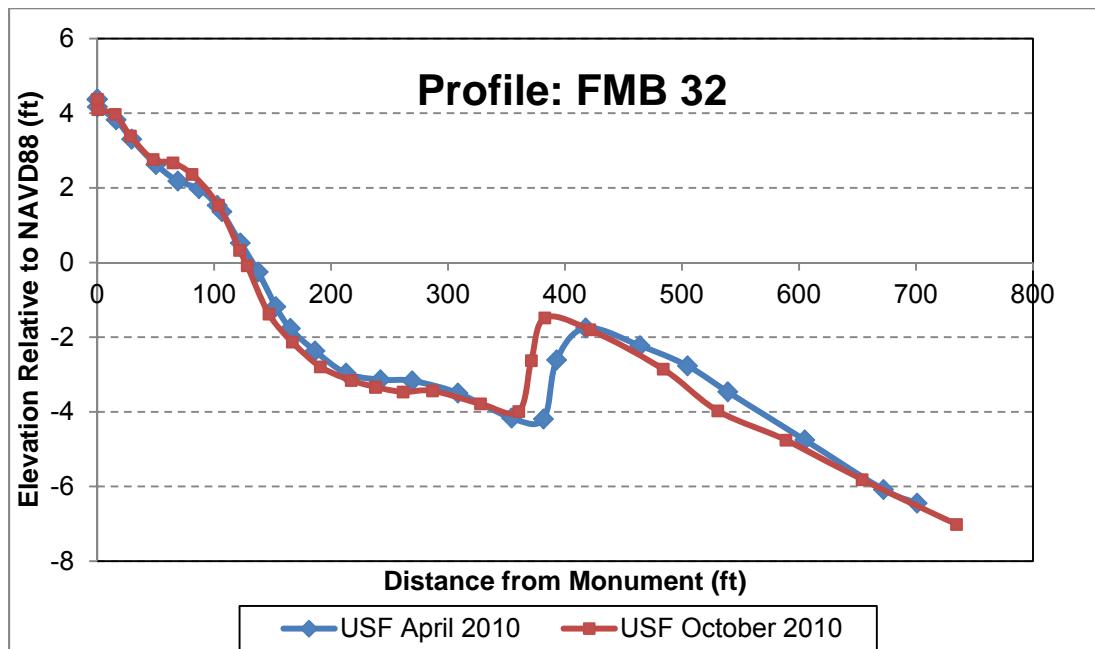


Figure G33. Beach Profile at FMB 32.

Appendix G. (Continued)

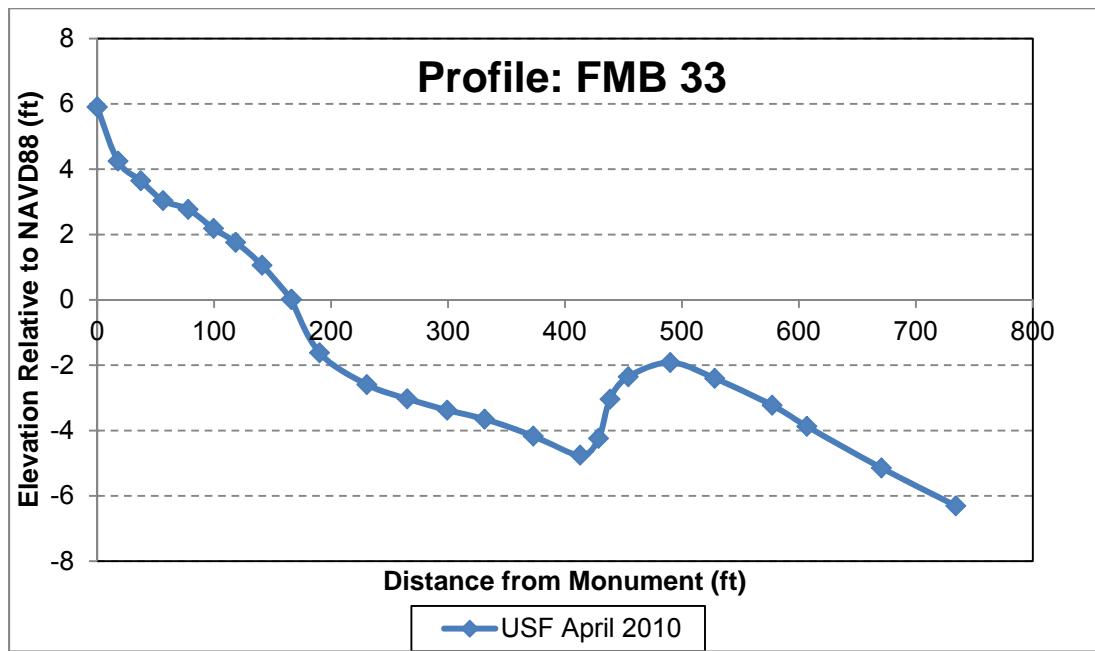


Figure G34. Beach Profile at FMB 33.

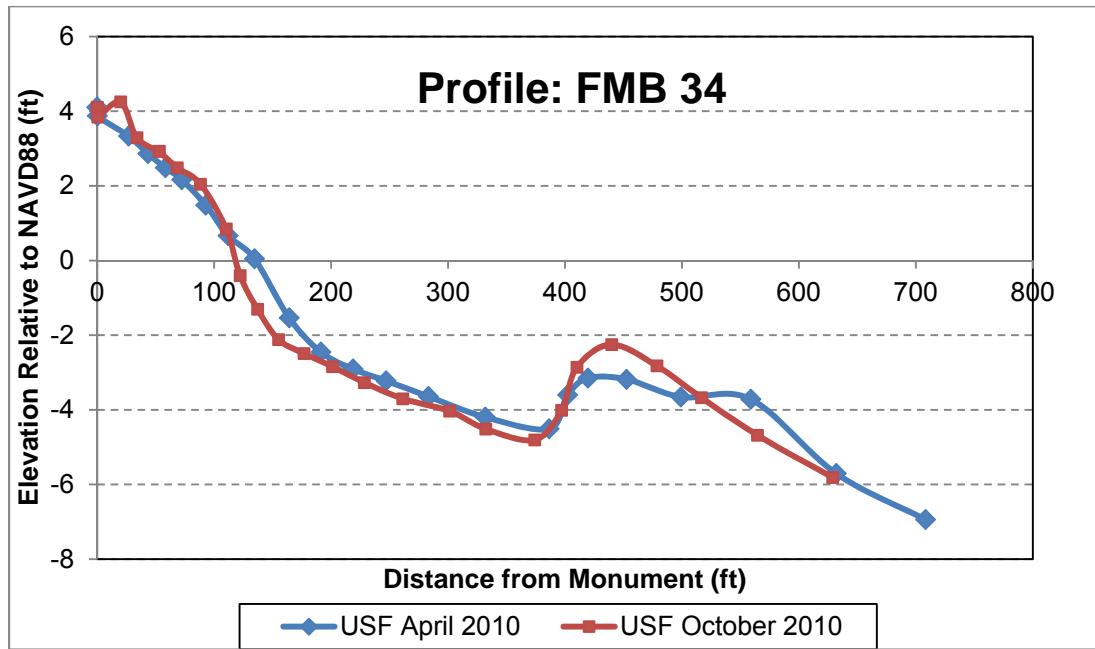


Figure G35. Beach Profile at FMB 34.

Appendix G. (Continued)

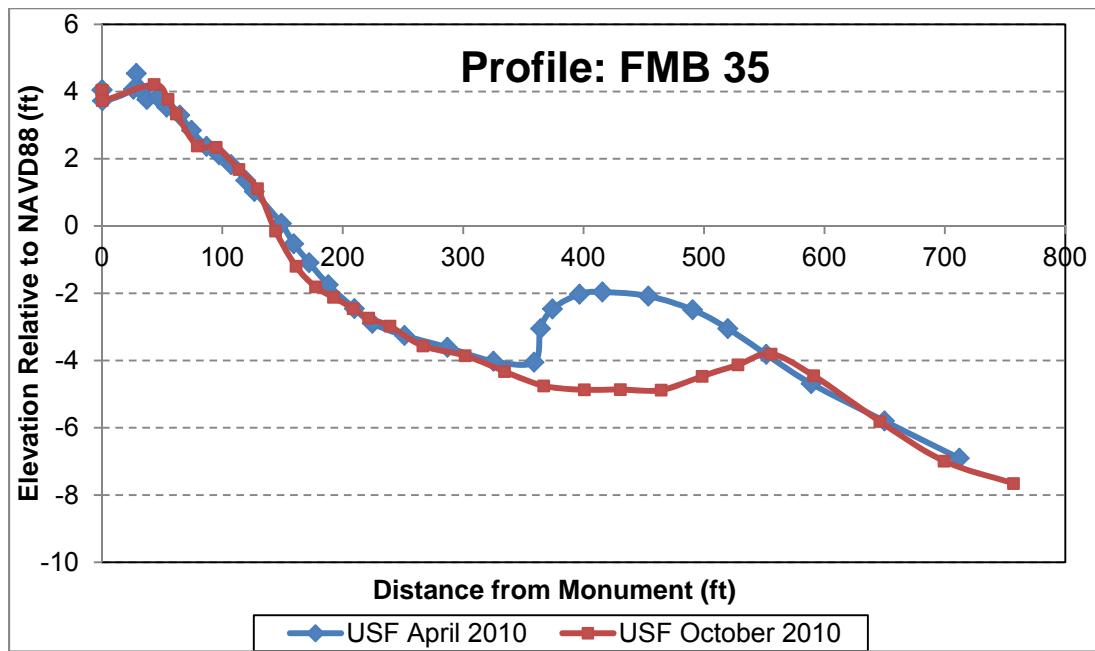


Figure G36. Beach Profile at FMB 35.

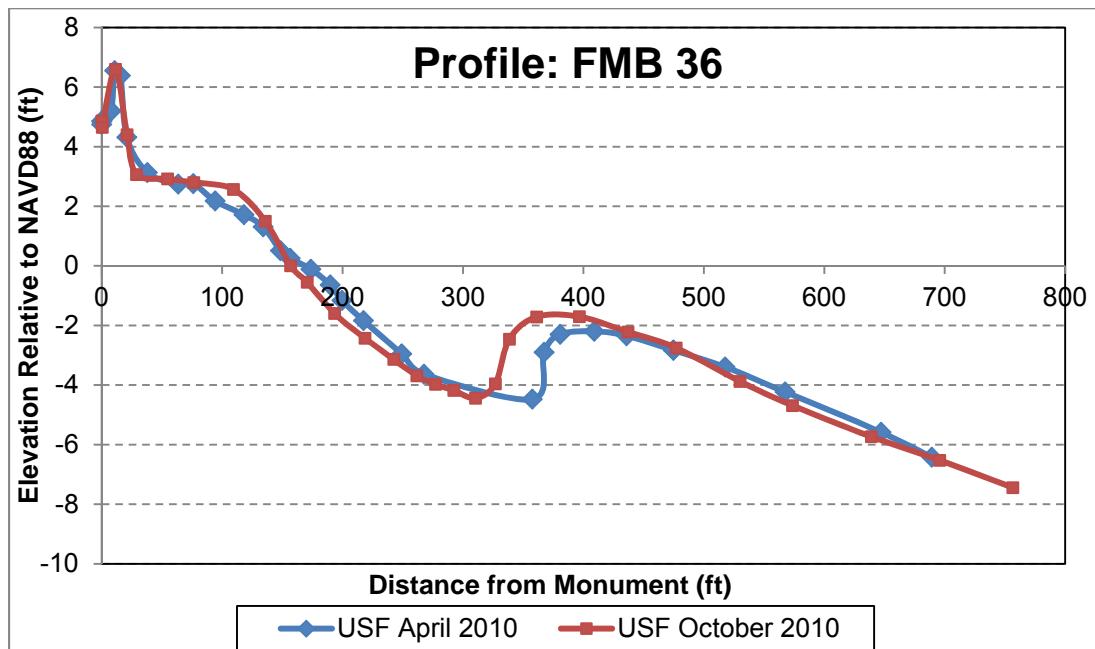


Figure G37. Beach Profile at FMB 36.

Appendix G. (Continued)

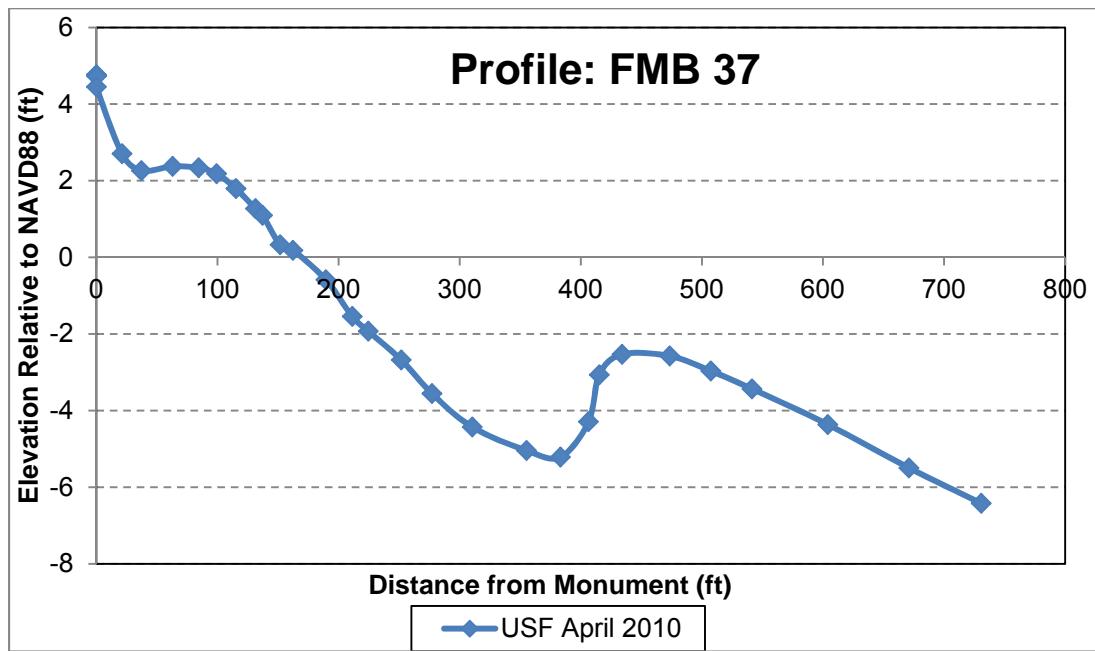


Figure G38. Beach Profile at FMB 37.

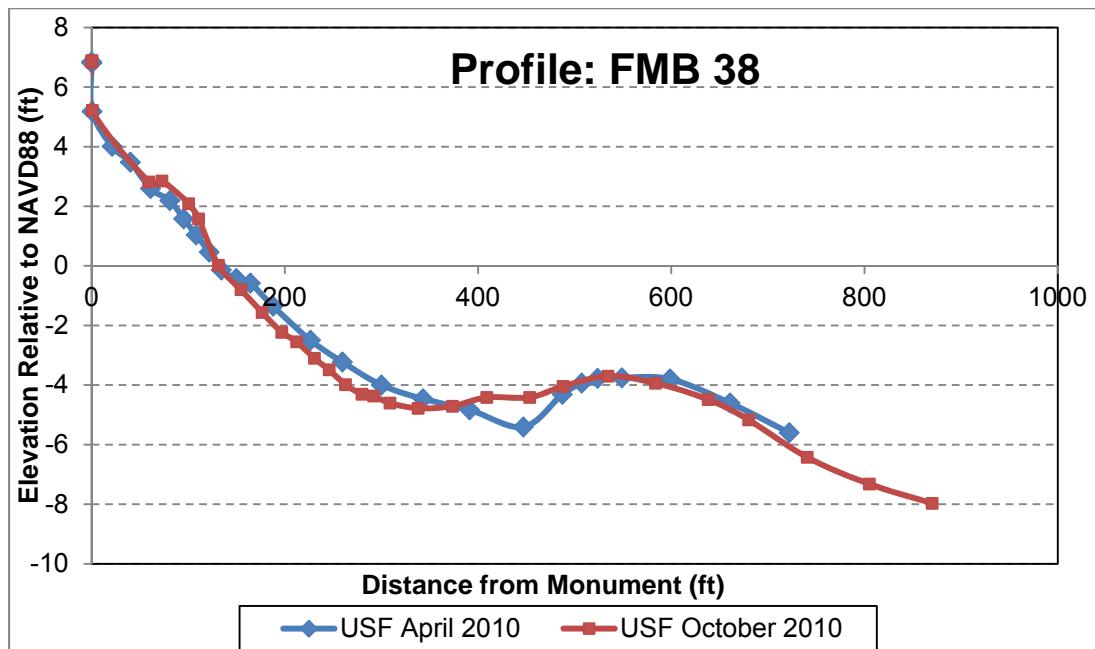


Figure G39. Beach Profile at FMB 38.

Appendix G. (Continued)

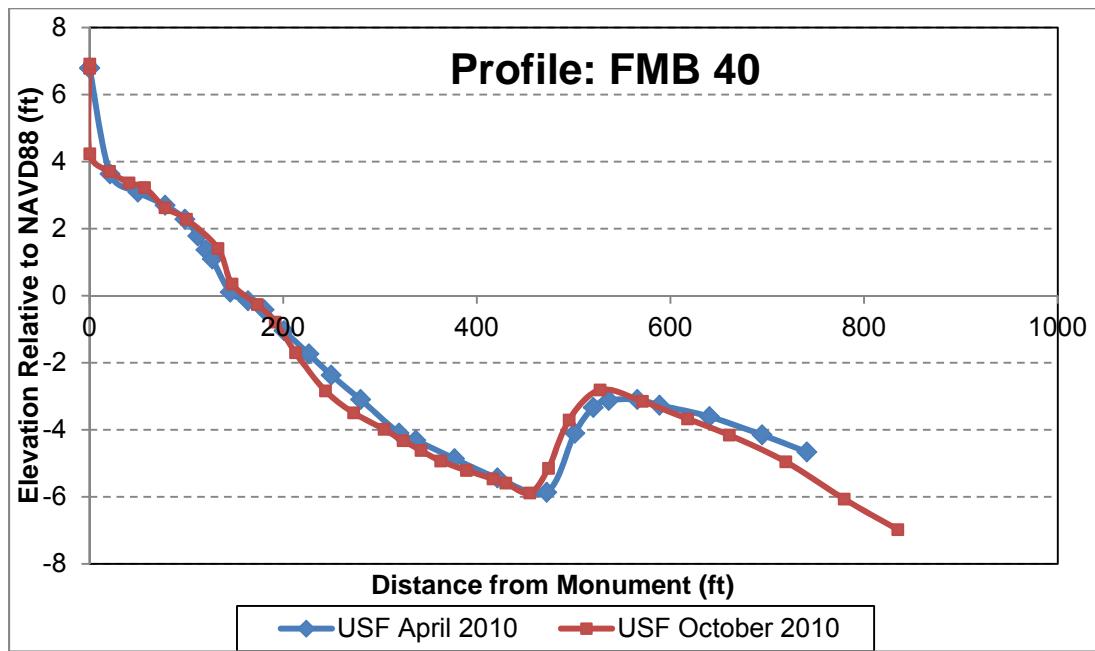


Figure G40. Beach Profile at FMB 40.

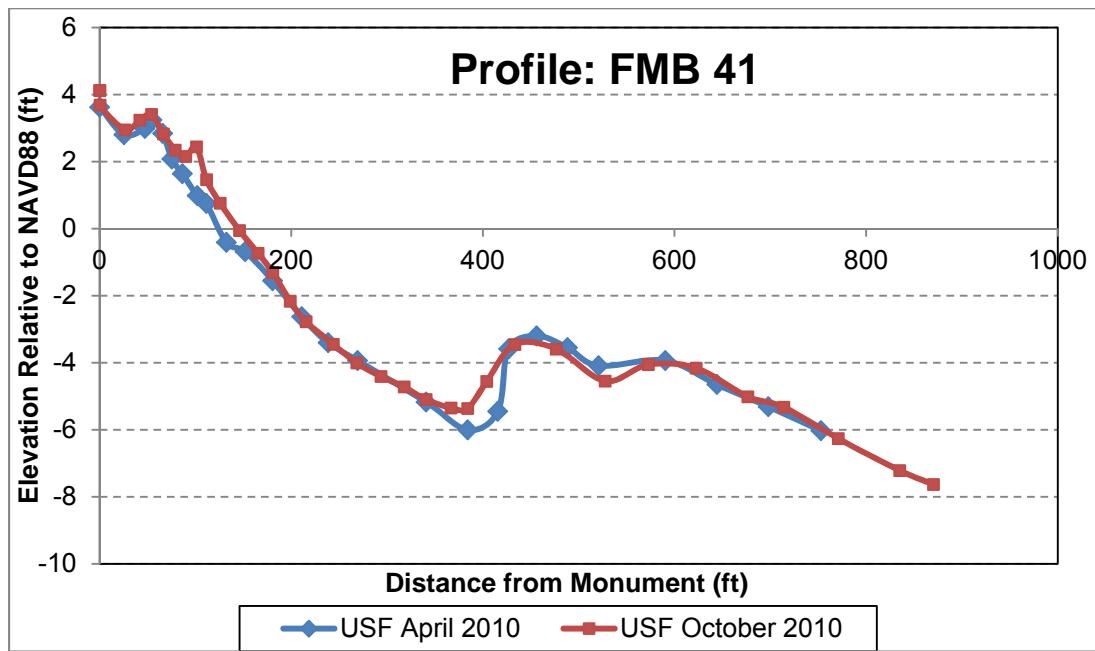


Figure G41. Beach Profile at FMB 41.

Appendix G. (Continued)

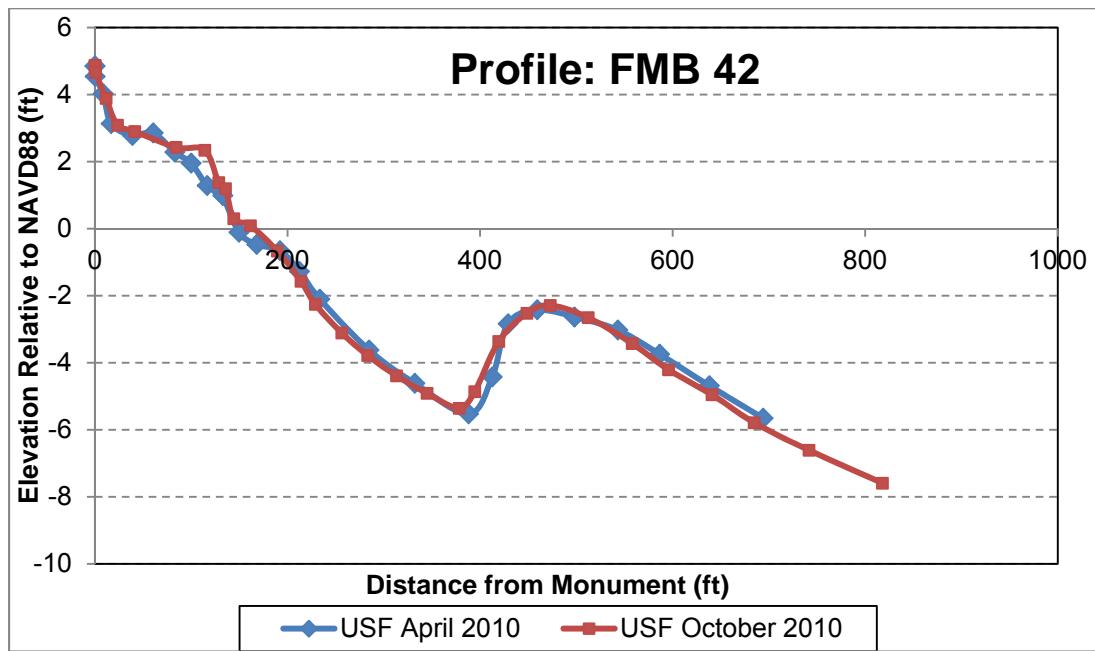


Figure G42. Beach Profile at FMB 42.

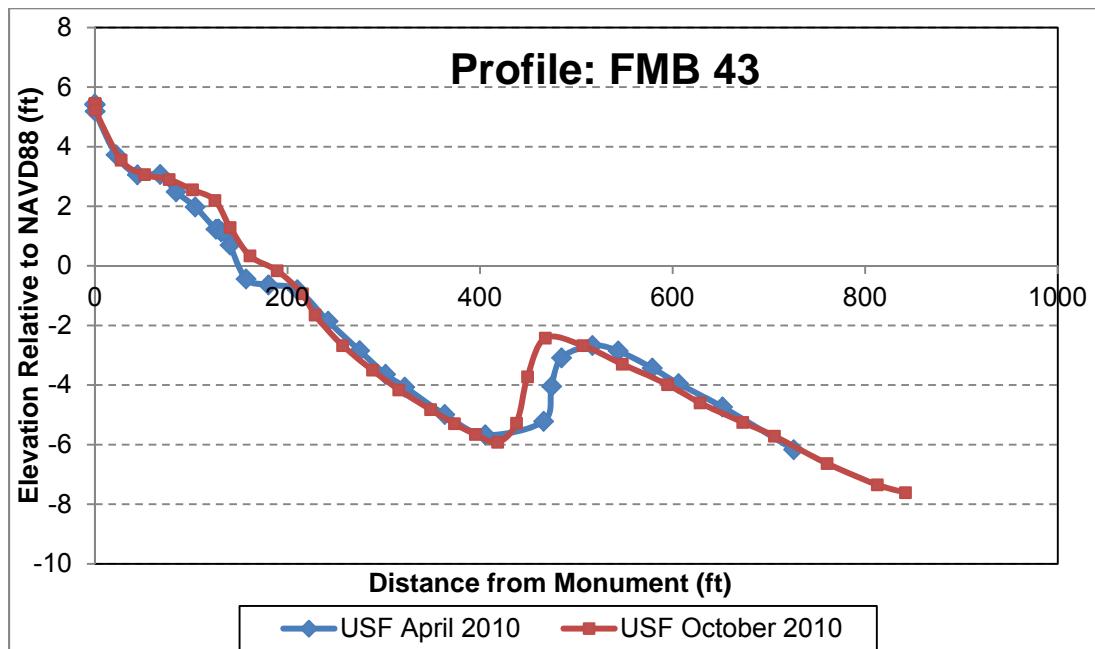


Figure G43. Beach Profile at FMB 43.

Appendix G. (Continued)

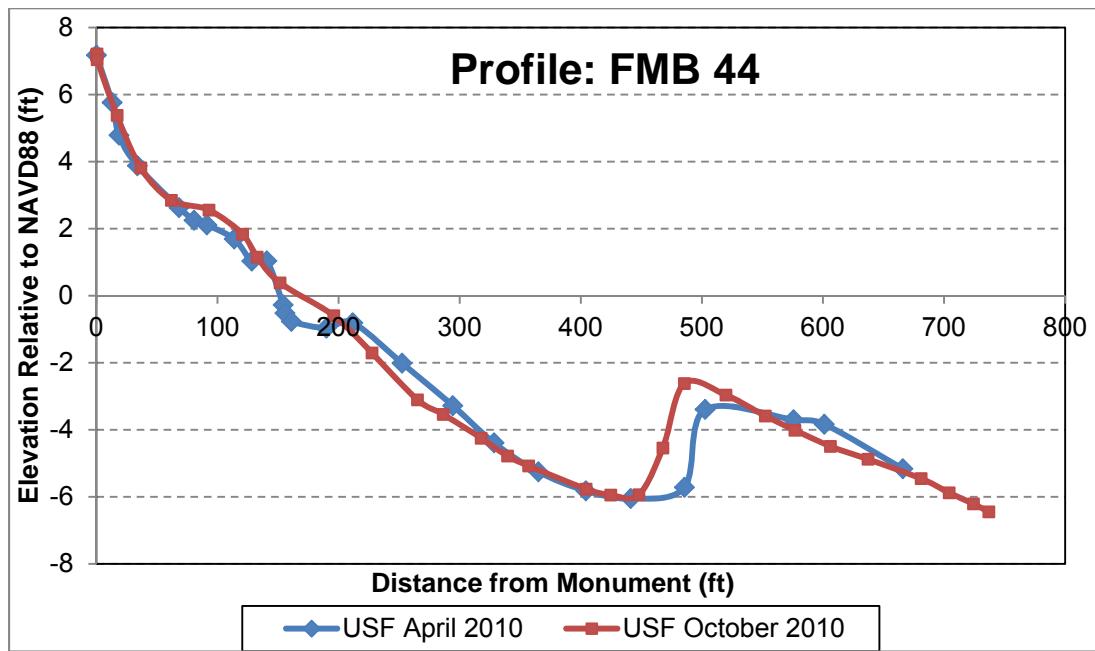


Figure G44. Beach Profile at FMB 44.

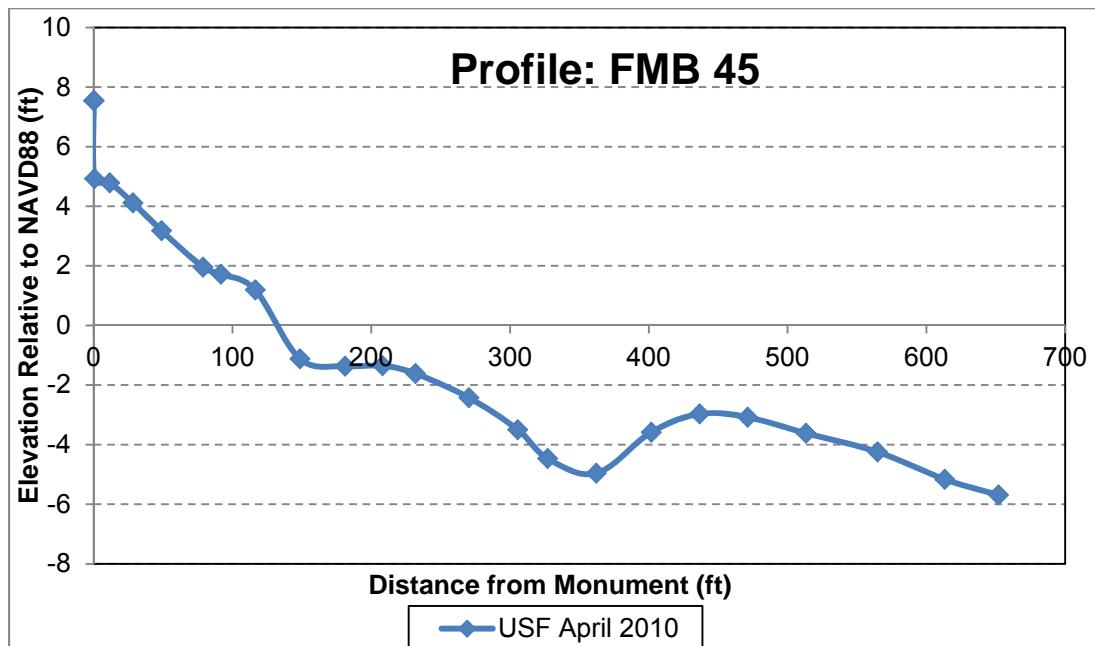


Figure G45. Beach Profile at FMB 45.

Appendix G. (Continued)

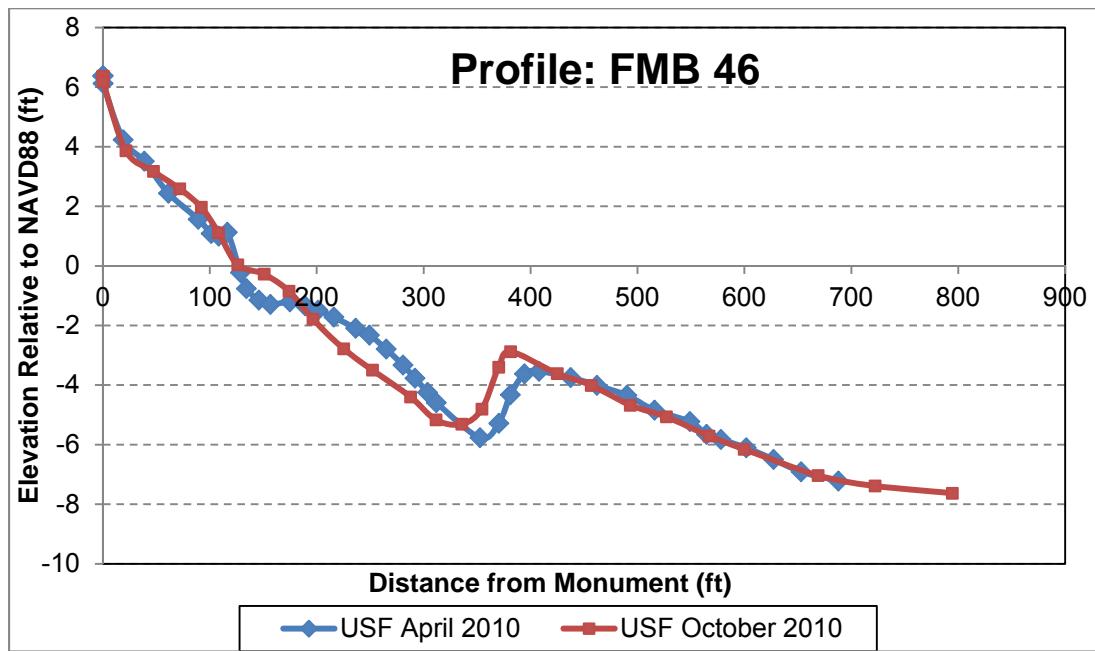


Figure G46. Beach Profile at FMB 46.

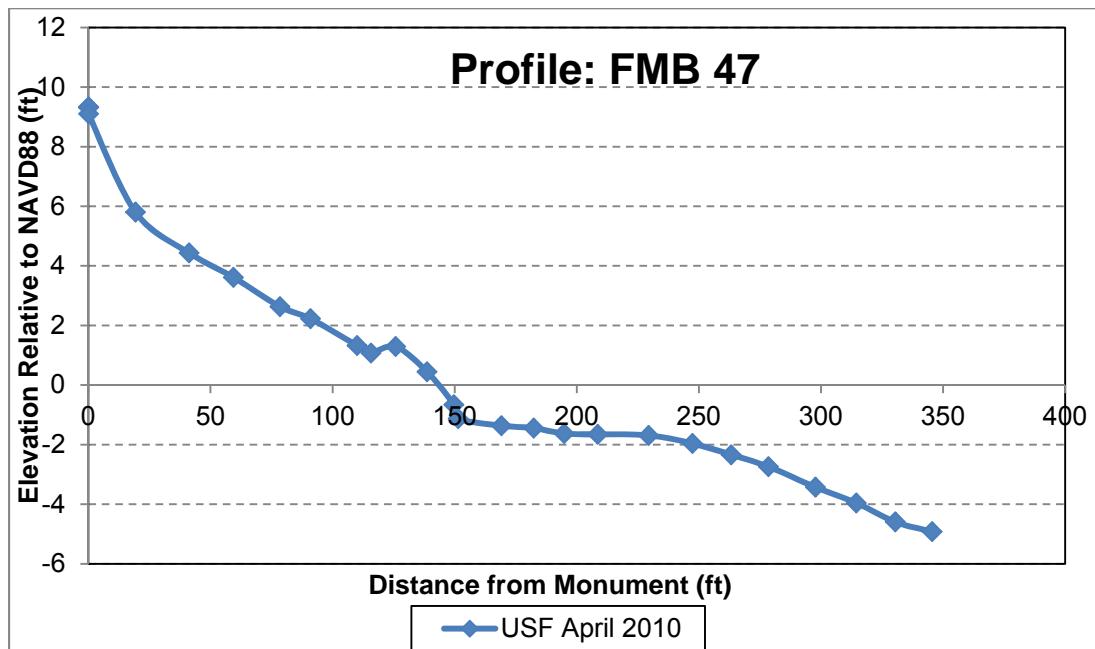


Figure G47. Beach Profile at FMB 47.

Appendix G. (Continued)

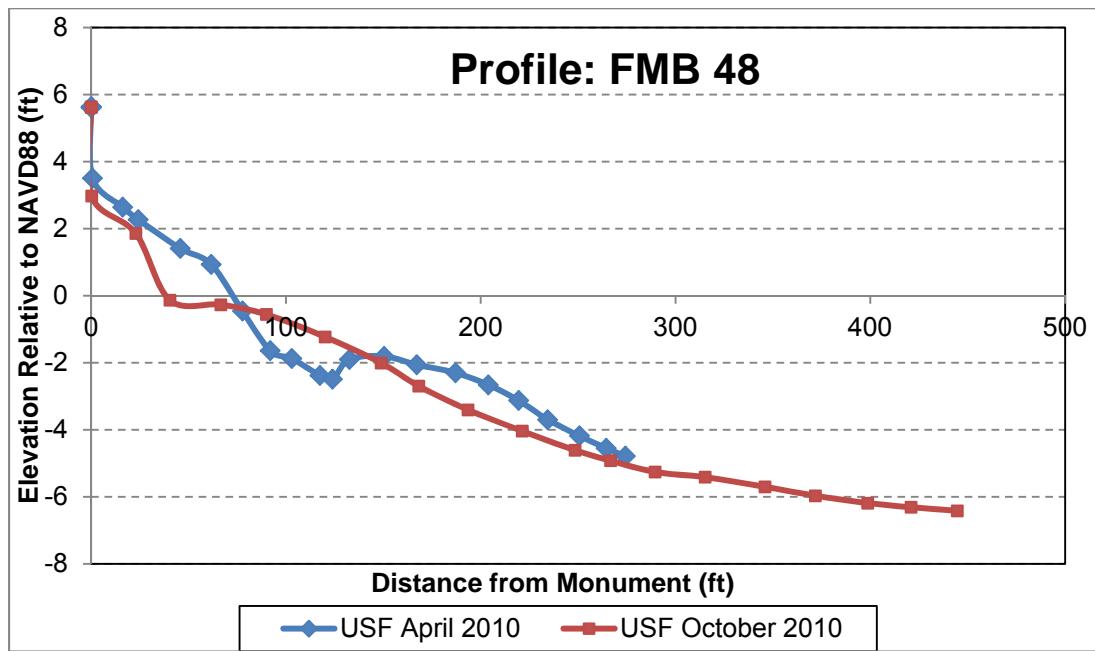


Figure G48. Beach Profile at FMB 48.

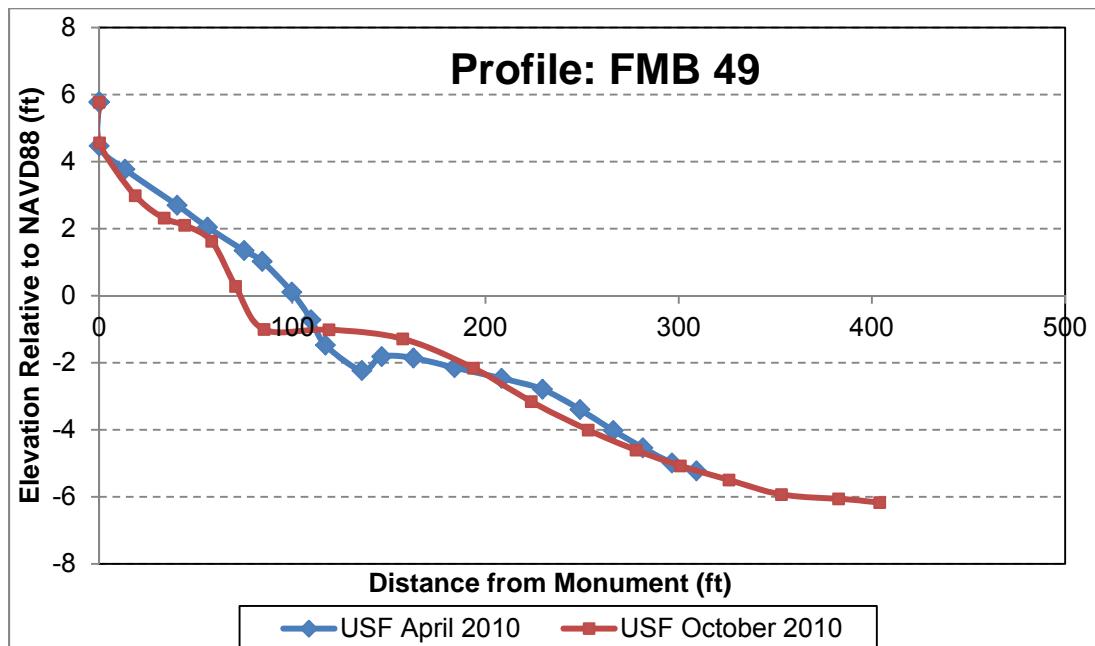


Figure G49. Beach Profile at FMB 49.

Appendix G. (Continued)

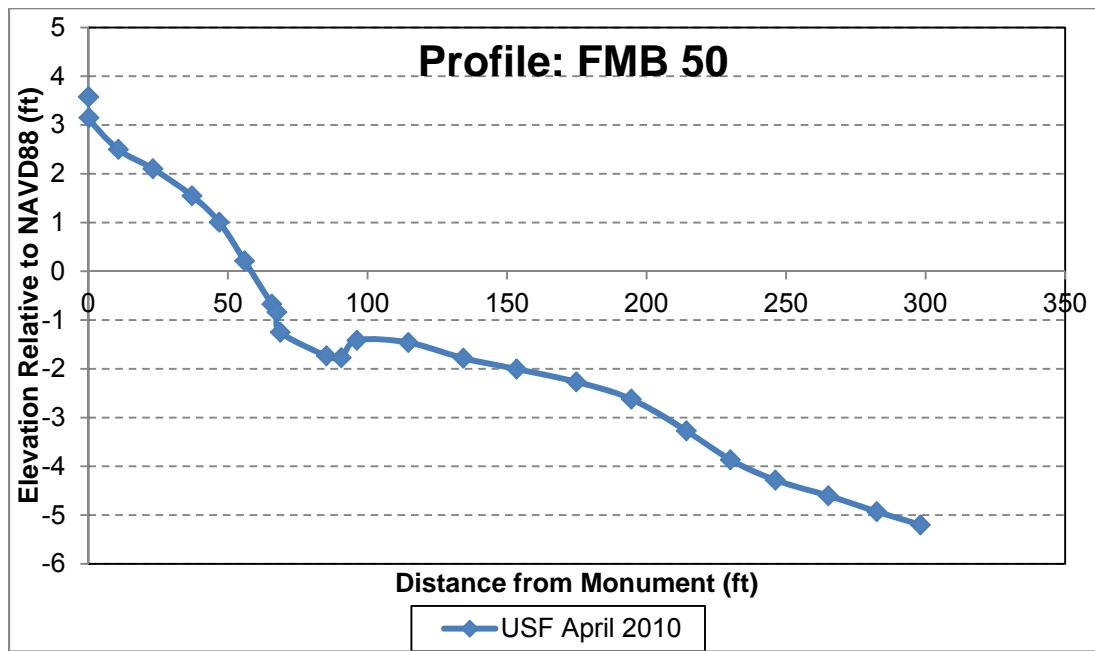


Figure G50. Beach Profile at FMB 50.

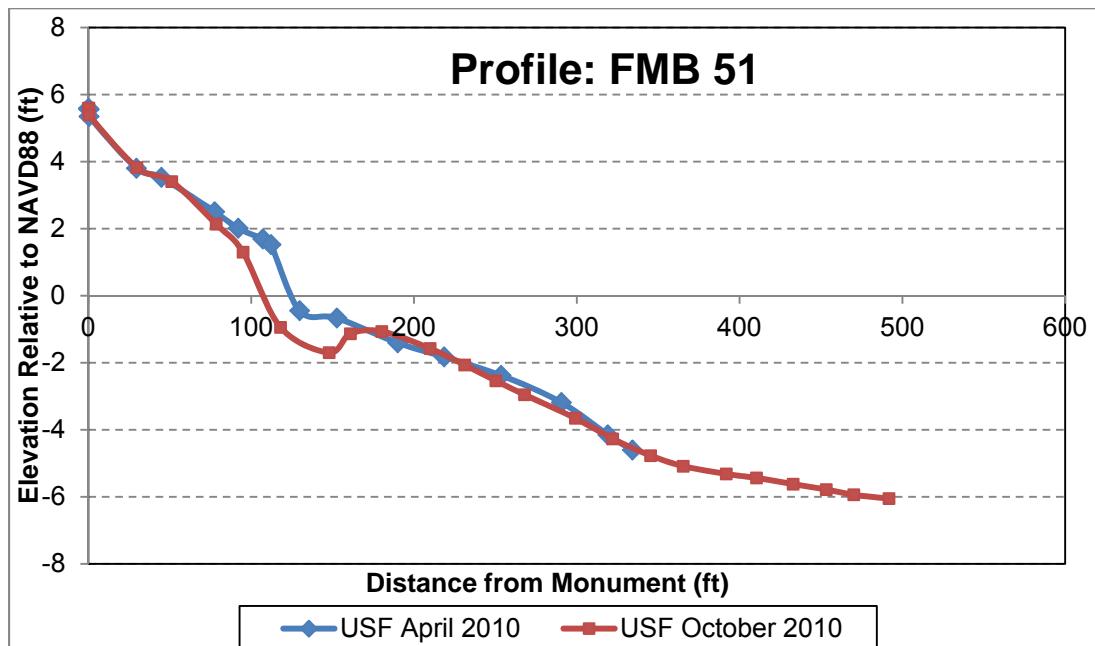


Figure G51. Beach Profile at FMB 51.

Appendix G. (Continued)

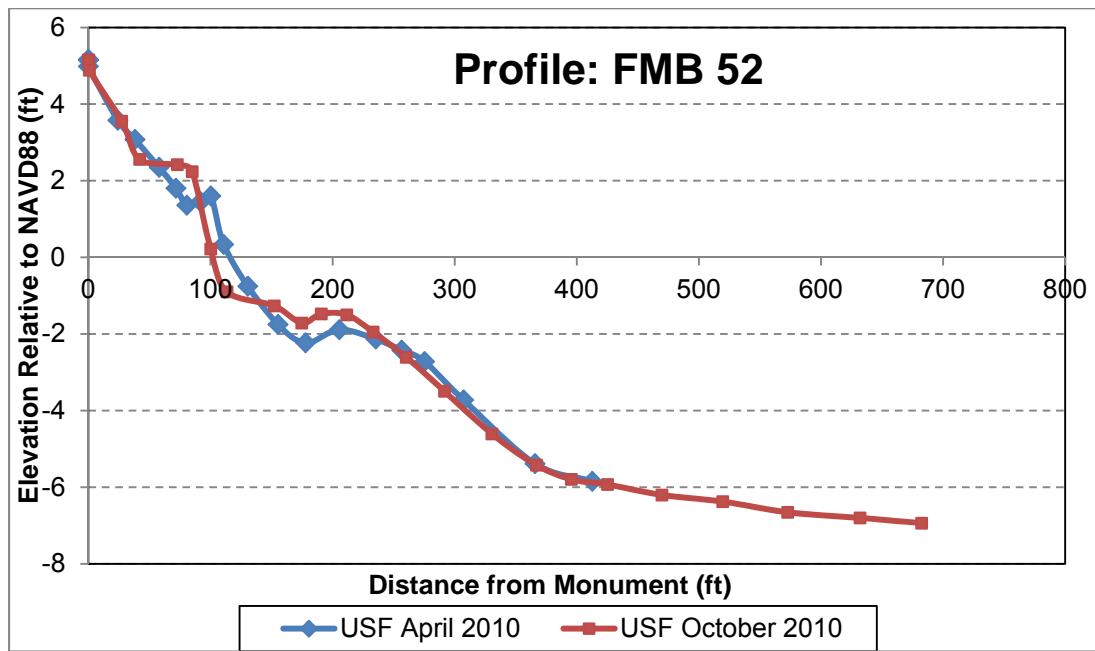


Figure G52. Beach Profile at FMB 52.

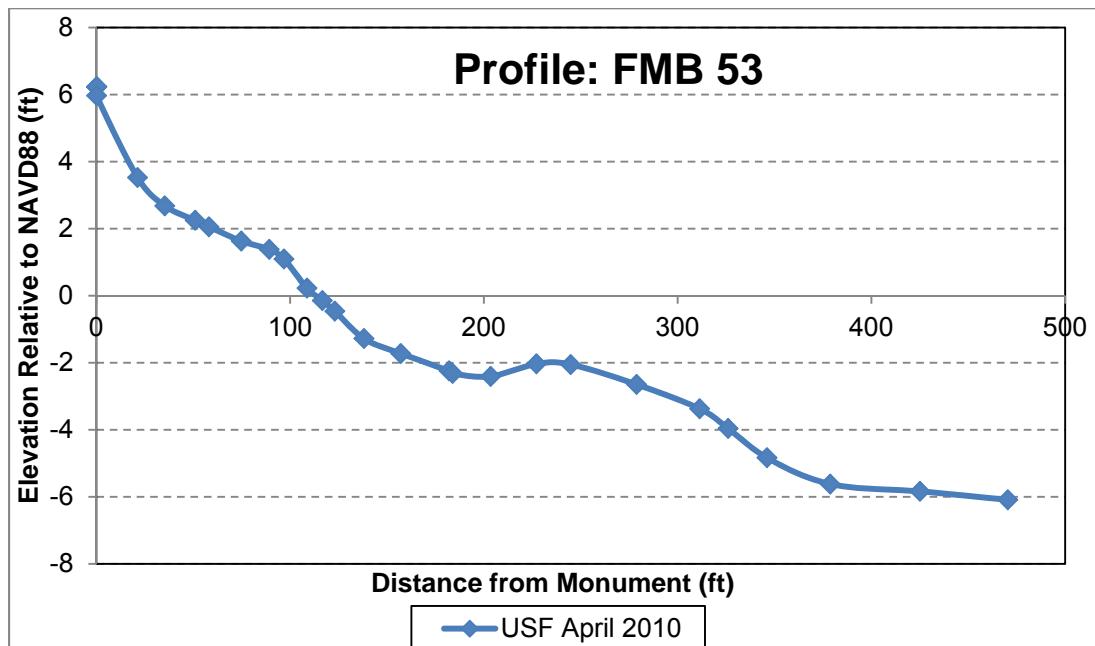


Figure G53. Beach Profile at FMB 53.

Appendix G. (Continued)

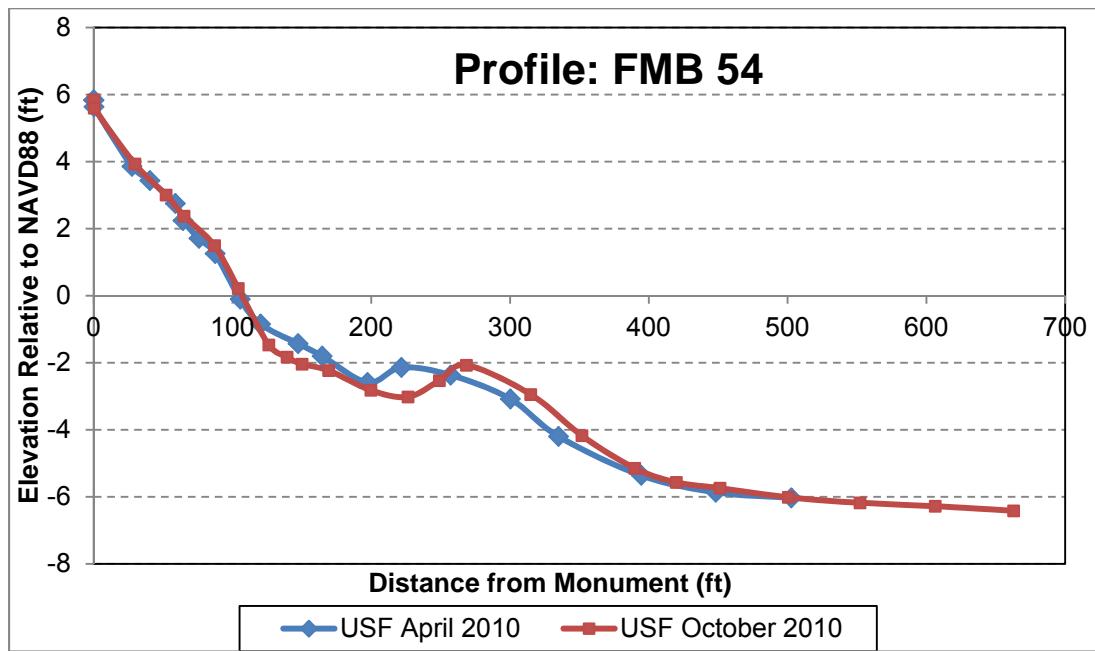


Figure G54. Beach Profile at FMB 54.

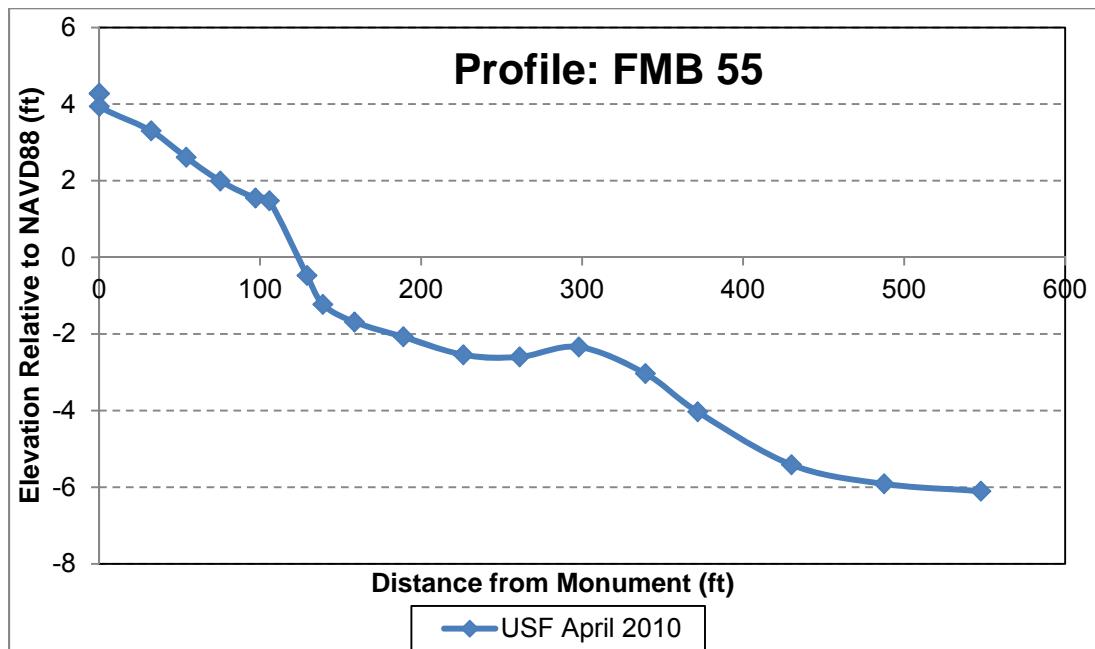


Figure G55. Beach Profile at FMB 55.

Appendix G. (Continued)

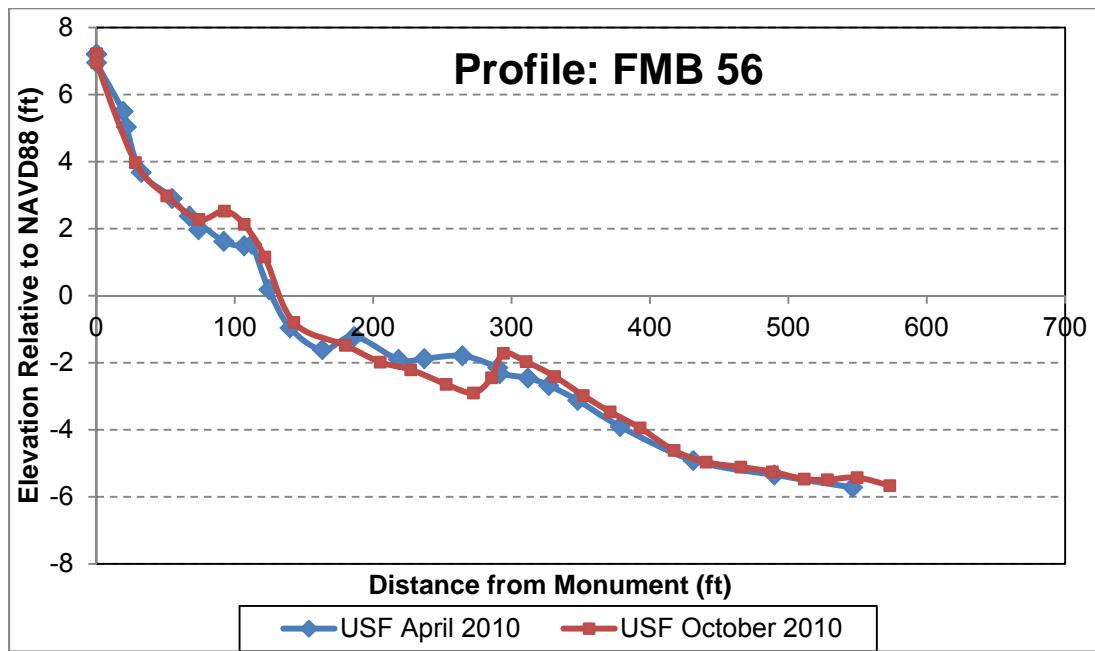


Figure G56. Beach Profile at FMB 56.

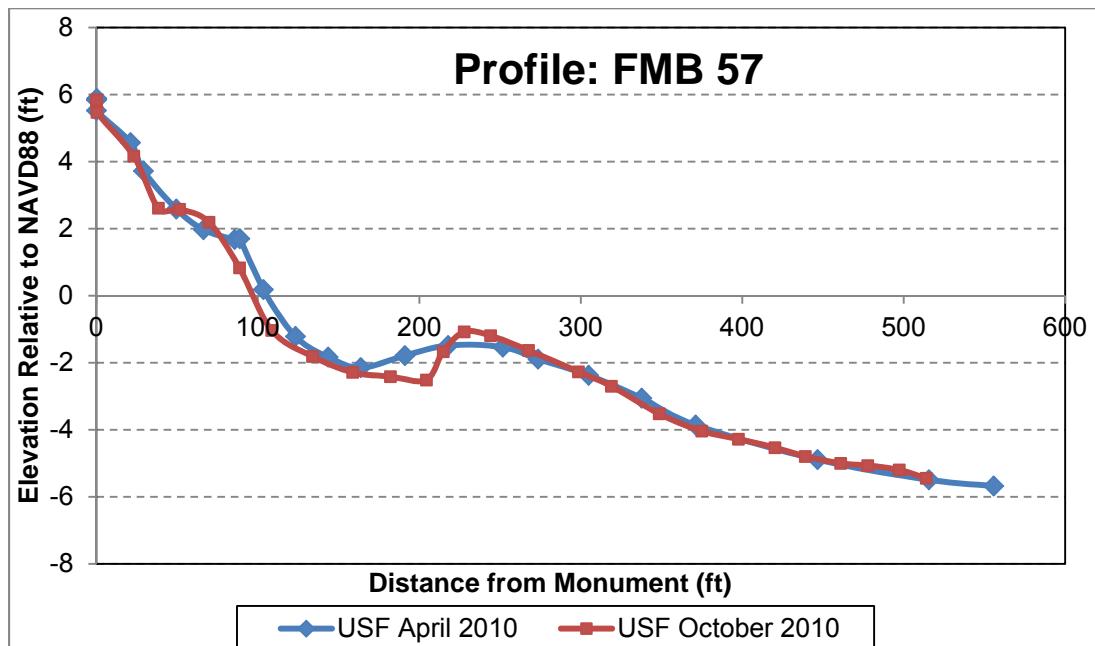


Figure G57. Beach Profile at FMB 57.